EM Counterparts to GW Sources: O4 and beyond

Varun Bhalerao

IIT Bombay

GW170817 showed us…

- NS mergers cause short GRBs
  - And off-axis jets matter!
- Speed of gravity
- Lorentz invariance and equivalence principle
- Standard siren for H0
- Sites of R-process nucleosynthesis
  - NS indeed made of neutrons!
- Equation of state of ultra-dense matter

Score card

GW170817

- 2993 days
- 2495 papers

Post-2018

- 2705 GCNs
- 542 from LVK

Kitne counterparts the?

What we've learnt since…

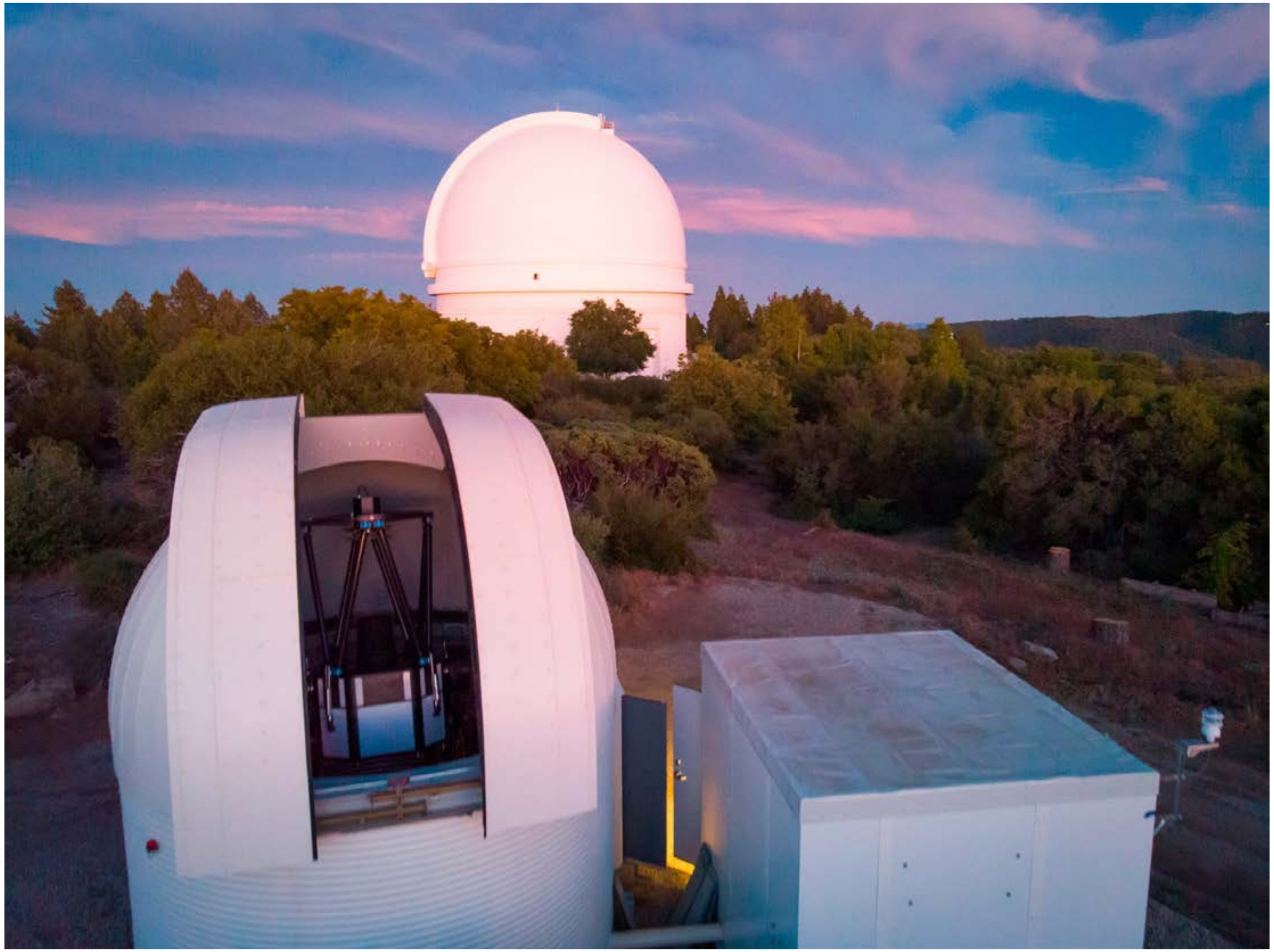
- Counterparts are faint!
- Rates are low!
- We are @#$!&# !
- Or are we?
- Goal: first find, then study

To find counterparts: be better at everything!

- Sensitive all-sky high-energy monitor
- Wide-field UV for catching the early flash
- Deeper optical surveys
- Wide-field IR surveys
- Deep radio searches?
  - SKA? DSA-2000?

Infra-red

- Palomar Gattini
  - 0.3m, 25 deg^2, J mag ~16
- WINTER
  - 1m, 1.2 deg^2, J mag ~ 18.5
- Cryoscope: Antarctica
  - 1m, 50 deg^2, J mag ~ 24 !
- PRIME: South Africa
  - 1.8m, 1.45 deg^2, J mag ~ 20
- DREAMS: Australia
  - 0.5m, 3.7 deg^2, J mag ~ 18



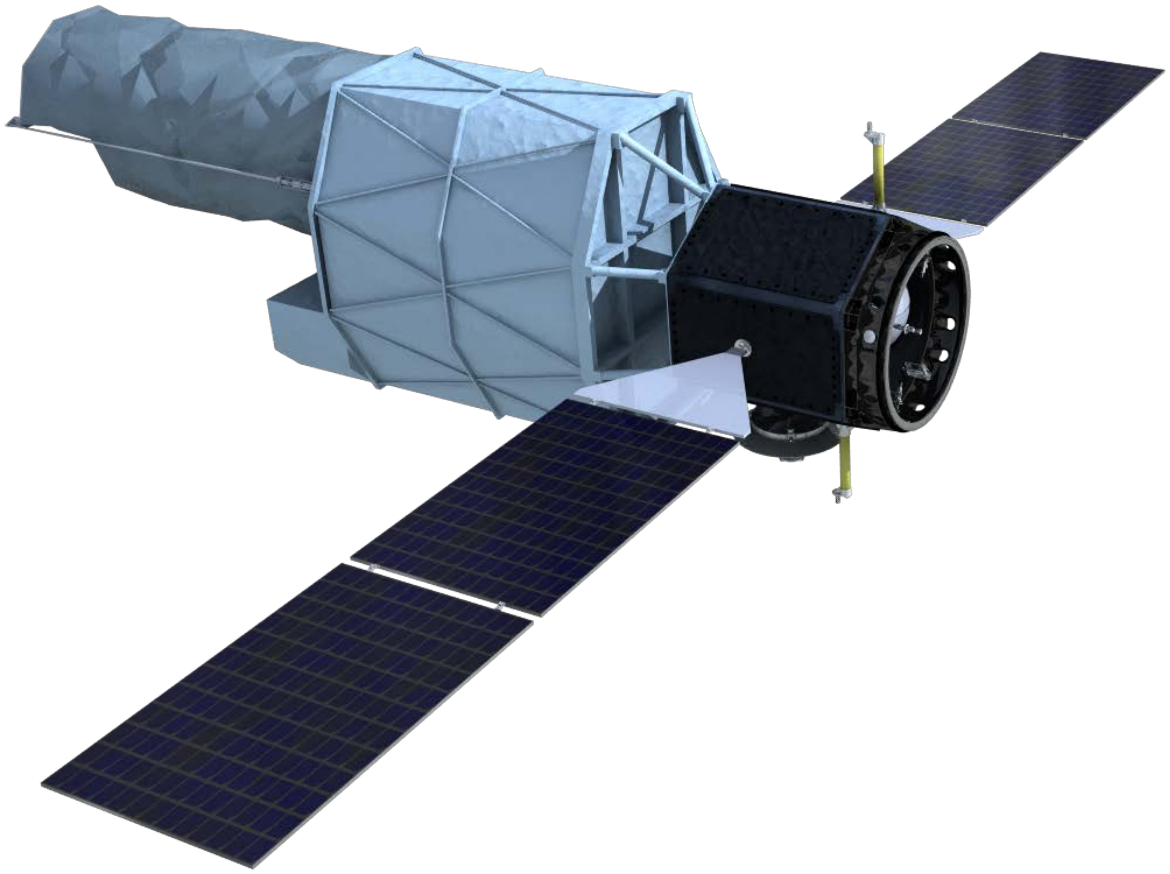
Optical

Zwicky Transient Facility

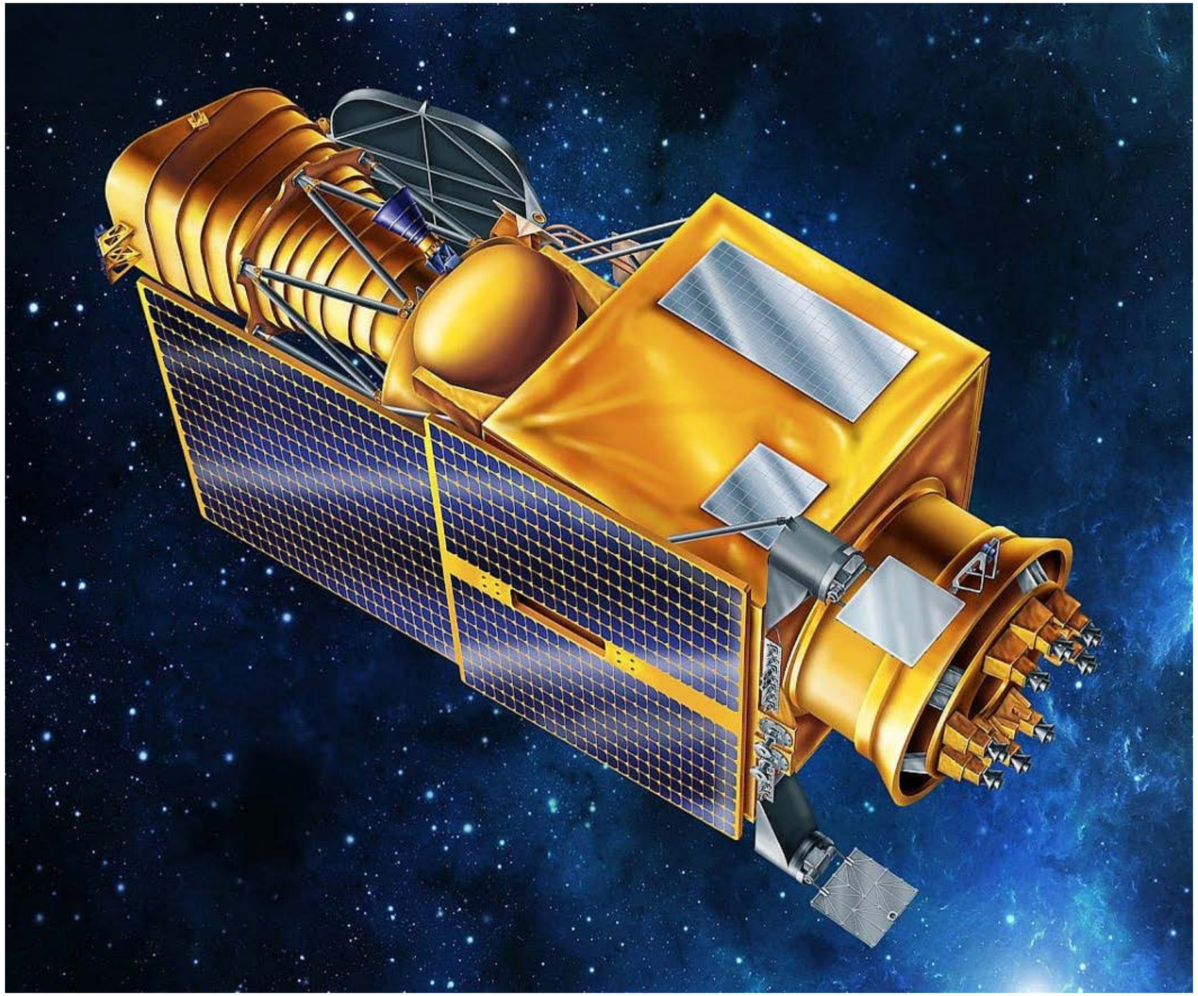
Vera Rubin Observatory

Ultraviolet satellites

UVEX: 0.75m, 12.3 deg^2, 25 mag



Ultrasat: 0.33m, 204 deg^2, 22-23 mag



Daksha – Indian Eyes on Transient Skies

Daksha

Based on Daksha Doc #209

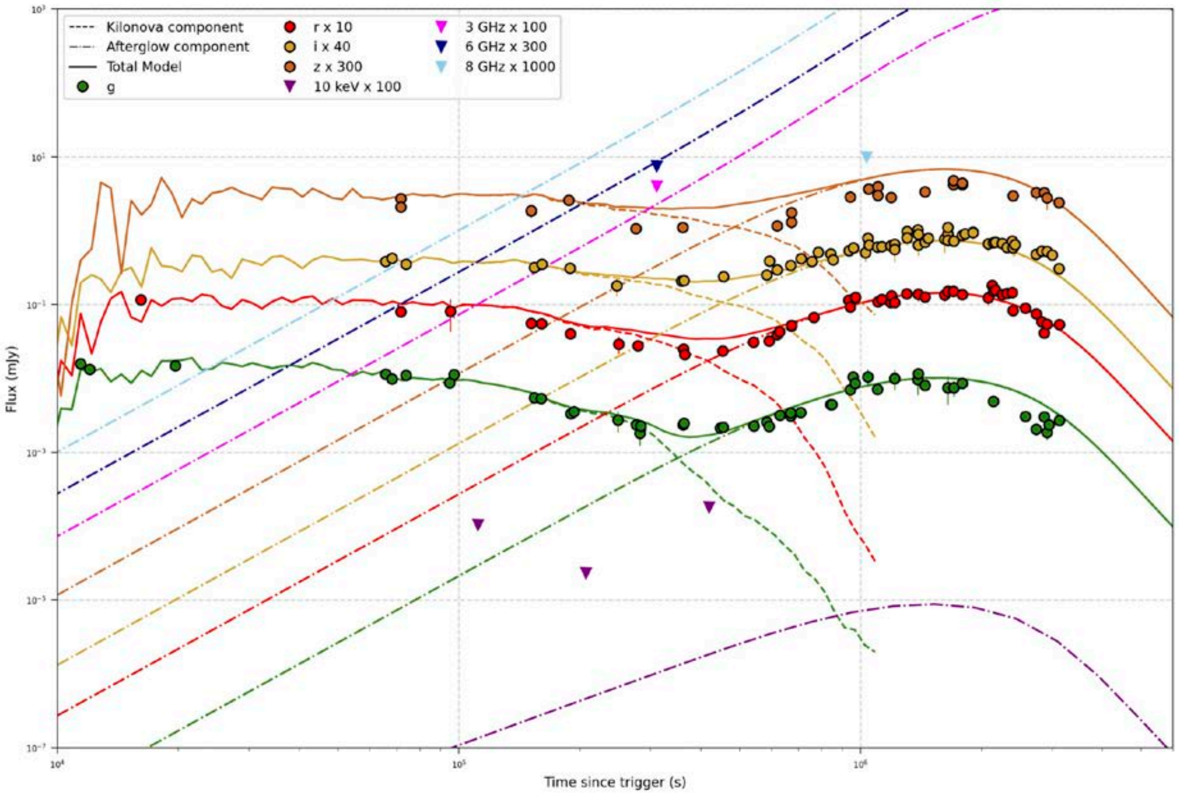
dakshasat.in

S250818k: NS merger candidate

What is it?

A kilonova + off-axis GRB afterglow?

A supernova?



Going forward: what should we do?

Better joint modelling

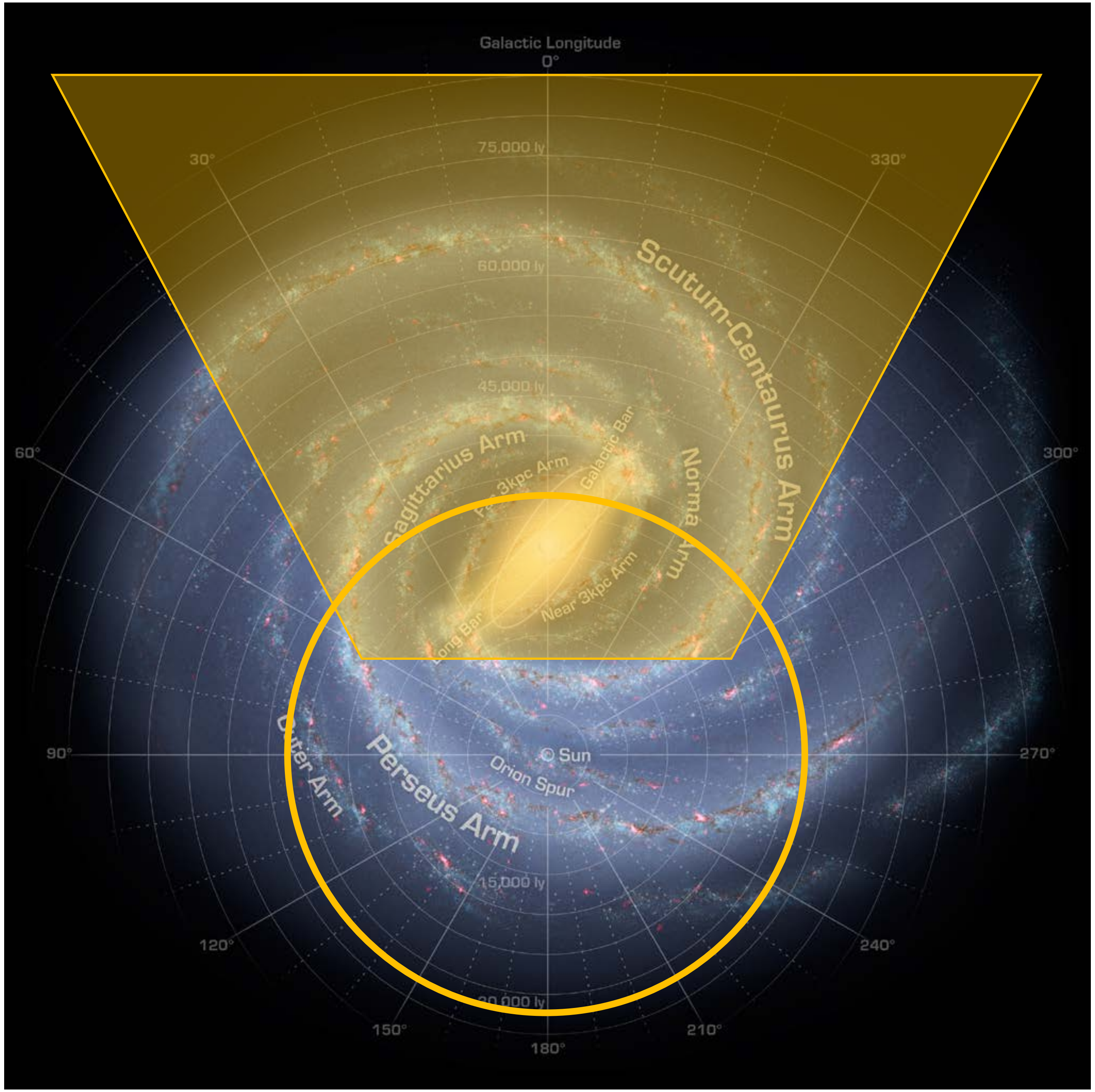
- Can GW PE + EM modelling be done jointly?
- Are models mature enough?
- How do we facilitate information exchange among multiple, potentially competing, groups?

Better joint searches

- Many candidates will be sub-threshold
- Can we agree on common FAR definitions?
- Even within GW?
- Statistical inferences instead of case-by-case?

Supernovae

- Range: our galaxy (say 10 kpc)
- Peak magnitudes
  - $M_V \sim -19.3$,
  - m_V (10 kpc) ~ -4.3
- Extinction!
  - IR Nova AT2023gde: $A_V \sim 24$
  - $m_V \sim 20$!
  - Can be much fainter
- Finding it:
  - Lot of optical surveys under way
  - IR surveys coming up



Supernovae: High energies

- Single degenerate:
  - MeV flash, 10 ms, 10^{44} ergs s^{-1} .
  - Peak flux: 8×10^{-3} ergs cm^{-2} s^{-1} .
  - Comparison: "BOAT" ~ 10^{-5} ergs cm^{-2} s^{-1} .
- Double degenerate:
  - Hard X-ray (50–200 keV), 10^3 s, 10^{47} ergs s^{-1} .
  - Peak flux: 8 ergs cm^{-2} s^{-1} .
- Everyone will see it
  - Most* detectors will saturate, cubesats will rule!

*… of course, this one will do well→

- Ref: Harms et al 2021

Remember CW sources!

- Isolated pulsars
- Accreting X-ray pulsars

- What EM data can help GW sources?
- Quantify the impact of searches given EM ephemeris

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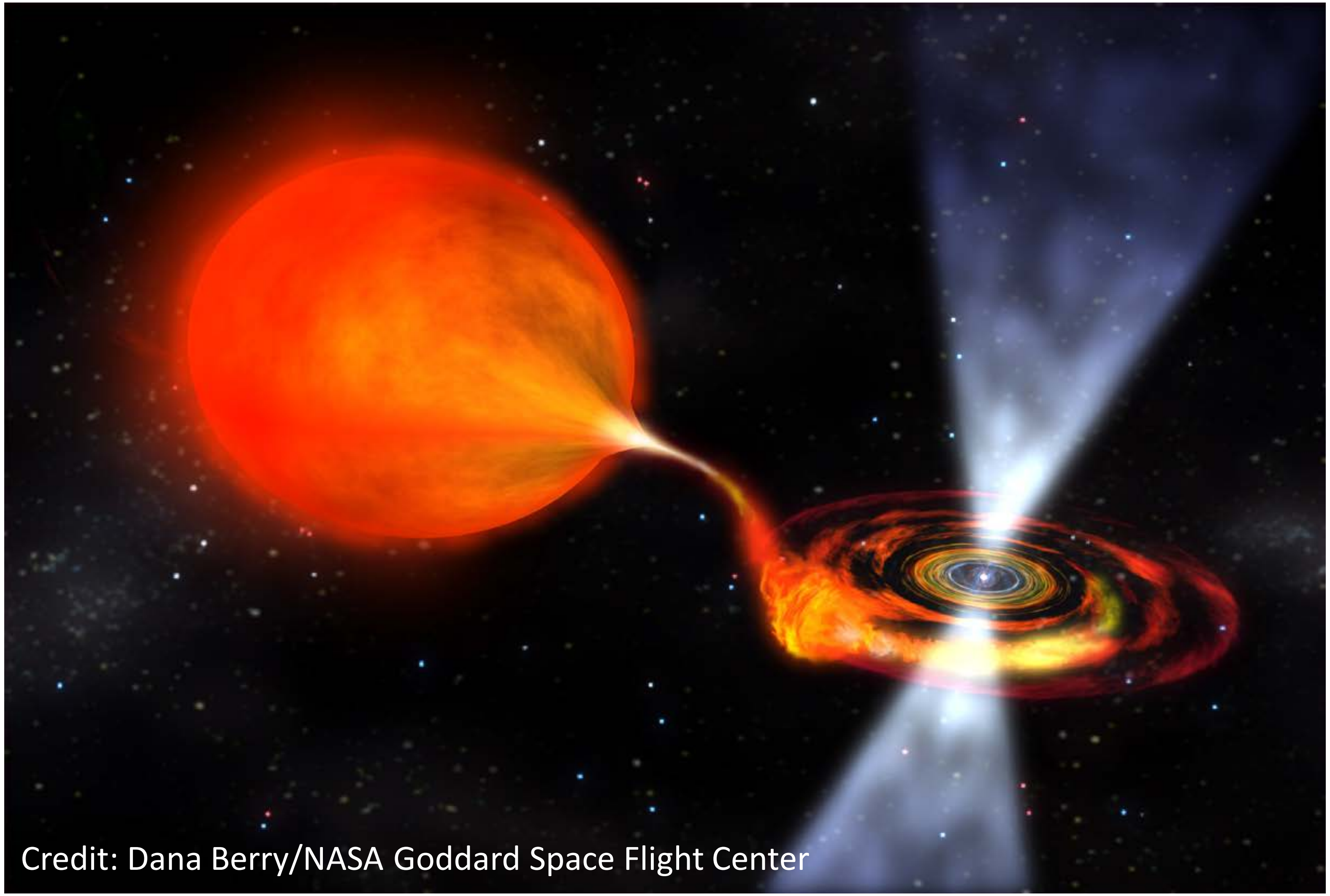

Daksha

Indian Eyes on Transient Skies!

For more details, visit **dakshasat**.in

The Daksha mission
will use a **pair of satellites**
to **continuously monitor**
the **entire sky**
for **high energy transients.**

dakshasat.in

Electromagnetic counterparts to GW sources

- Binary neutron star merger GW170817
- GW170817: more than 1300 refereed papers
- Scientific outcomes:
  - Confirmation of progenitors of Short Gamma-Ray Bursts
  - Cosmology: H_0
  - Sites of r-process nucleosynthesis
  - NS EOS

Beyond GW170817

- No electromagnetic counterparts detected in any band!

- Fluxes too faint for current telescopes!
- Typical optical surveys: ~21 mag
- IR surveys: 17-18 mag
- X-ray telescopes: ~ few × 10^{-7} ergs/cm^2/sec

Event	Dist (Mpc)	Area (sq deg)	Optical (r)	IR (Ks)	X-ray (10^{-8} cgs) (10 – 1000 keV)
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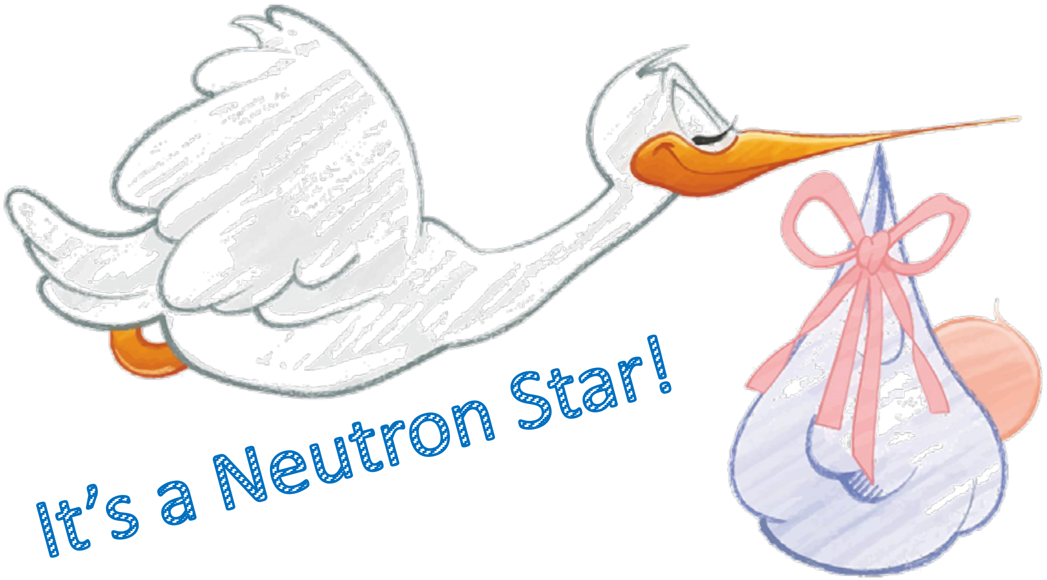
Why High-Energy observations?

- Fastest response
- Improved localisation
- Confirmation of existence of counterpart!



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↓ λ

Was there a neutron star?

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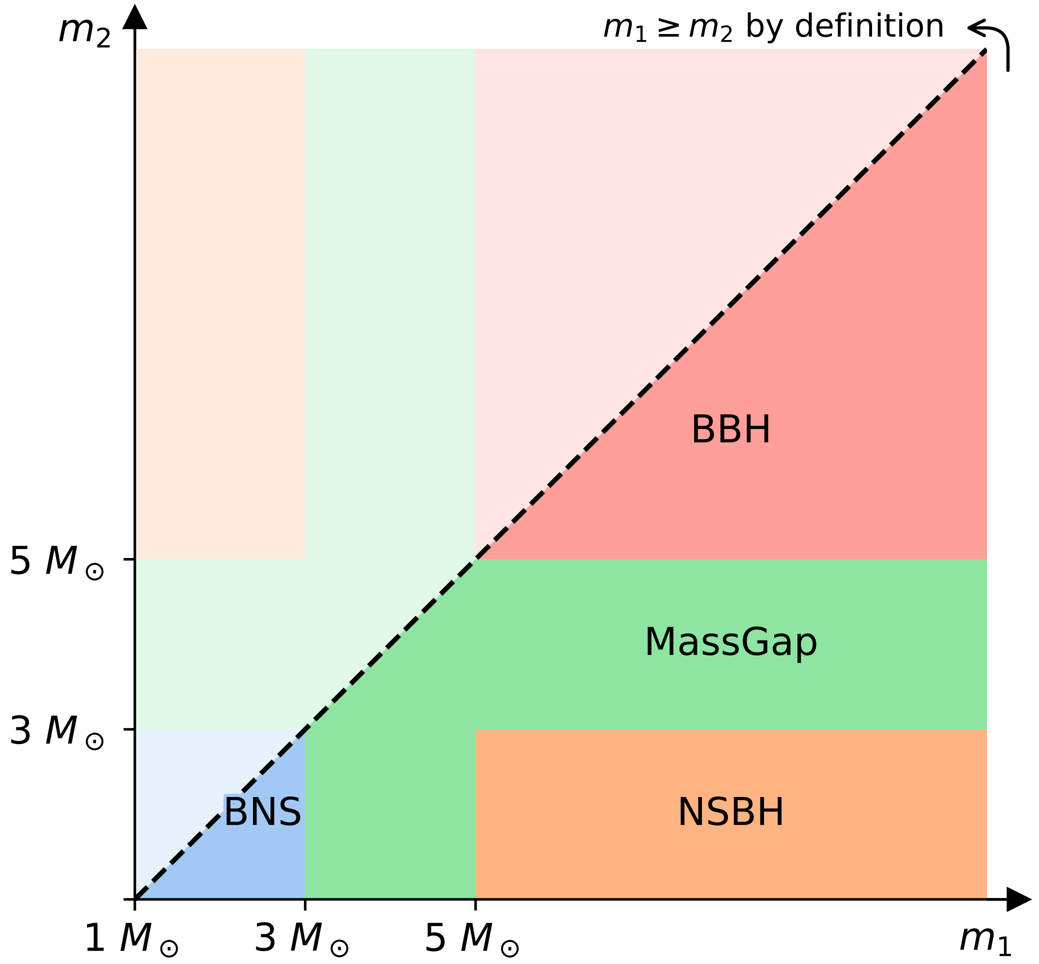


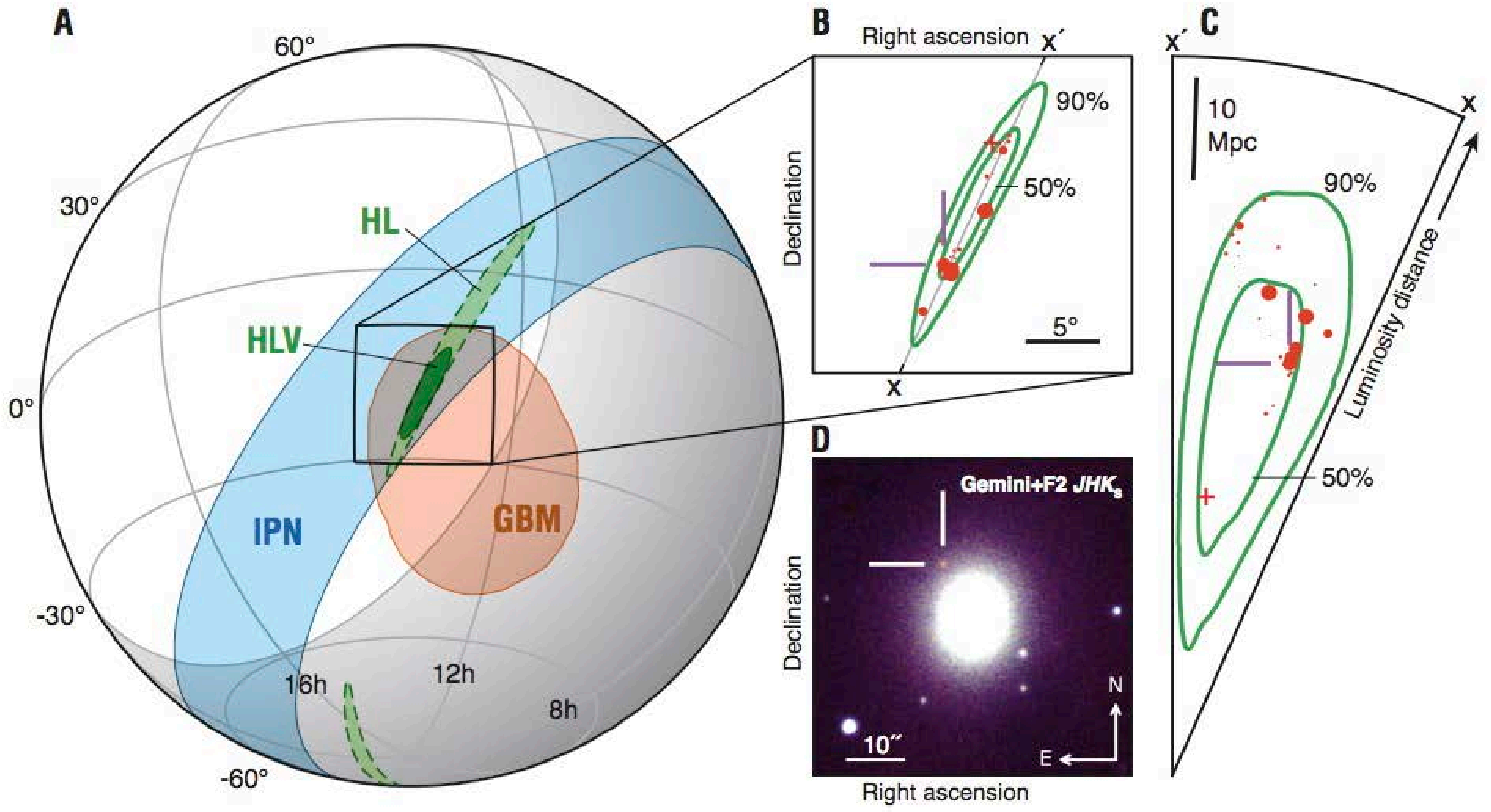
- Can MassGap objects emit EM radiation?
- S190930s, S190924h, S200115j, S200316bj

Who’s keeping watch?

GW170817: AstroSat

- Instantaneous sky coverage: ~70%
- Duty cycle: ~70–75%
  - ~25–30% SAA
- Effective coverage: ~50%

Limitation for all LEO satellites!



Requirements

Order of magnitude higher volumetric coverage

(Large area, lower noise, higher field of view)

Wide spectral band

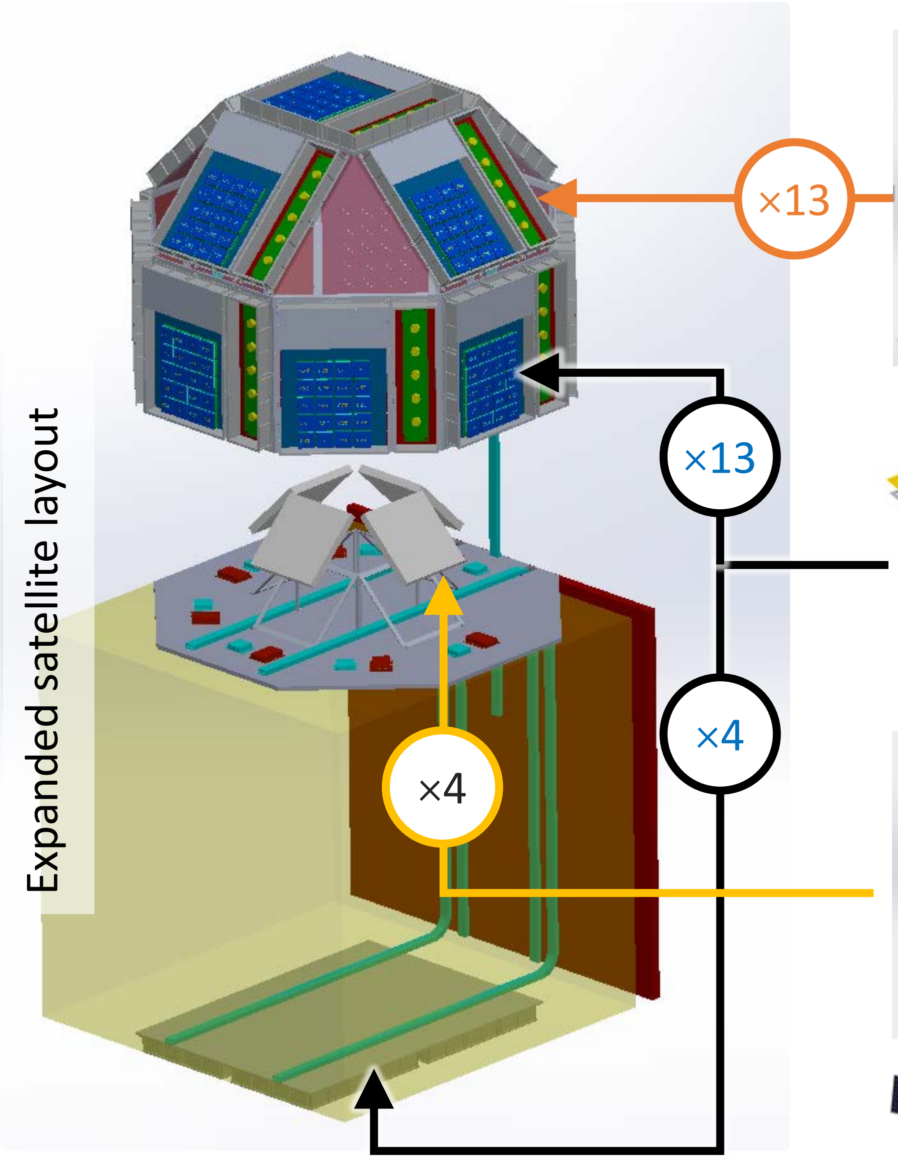
(1 keV to >1 MeV)

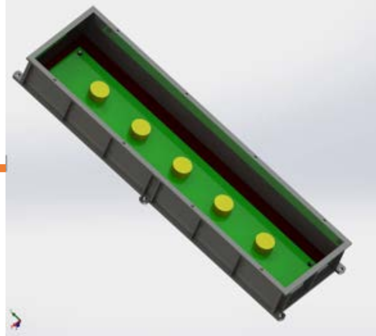
Continuous all-sky coverage

(Two satellites)

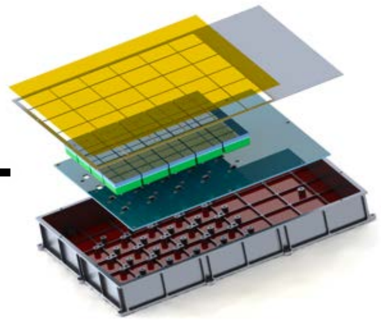
Daksha: technical overview

Bhalerao et al., 2024, ExA, 57, 24
https://arxiv.org/abs/**2211.12055**

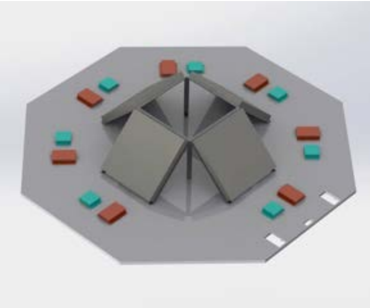




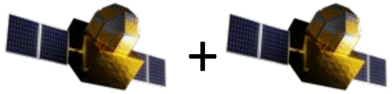
Low Energy (LE): Silicon Drift Detectors
Range: 1 – 30 keV
13 packages with 5 detectors each
Used for **Chandrayaan 2 XSM, Chandrayaan 3 APXS**



Medium Energy (ME): Cadmium Zinc Telluride detectors
Range: 20 – 200 keV
17 packages with 20 detectors each
Used in **Aditya-L1, AstroSat CZTI, RT2**, etc

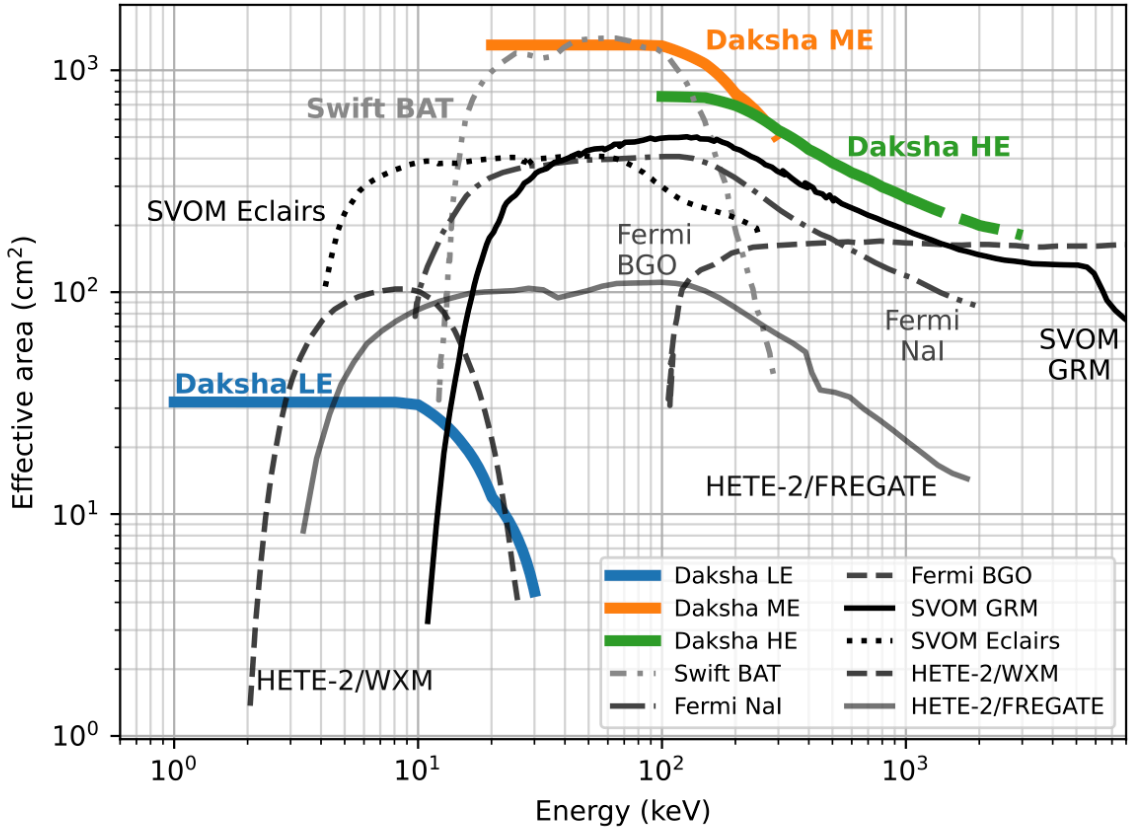


High Energy (HE): Sodium Iodide scintillator with Silicon Photo-Multipliers (NaI + SiPM)
Range: 100 keV – >1 MeV
Four detector units, **Multiple missions**



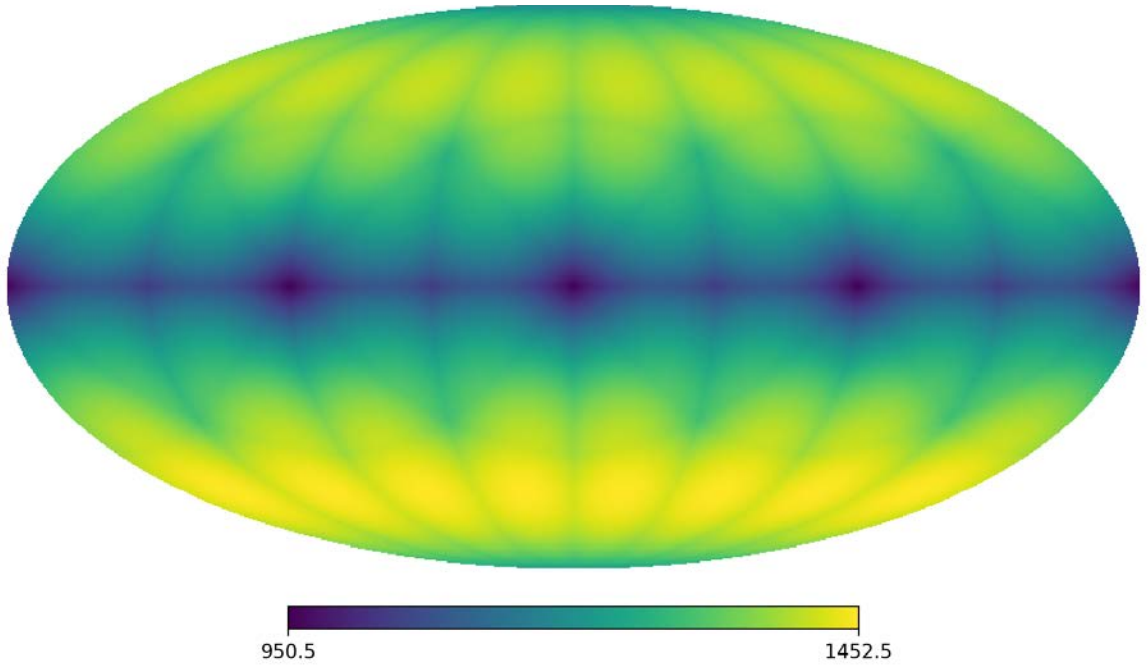
Two satellites for continuous all-sky coverage

Daksha effective area



Comparing with other missions

All-sky median value:
1300 cm^2 (single satellite)
1700 cm^2 (two satellites)



All-sky effective area

Comparing missions

- Daksha has the highest volumetric survey reach of any mission
- BAT-like sensitivity over the entire sky
- Wider spectral band

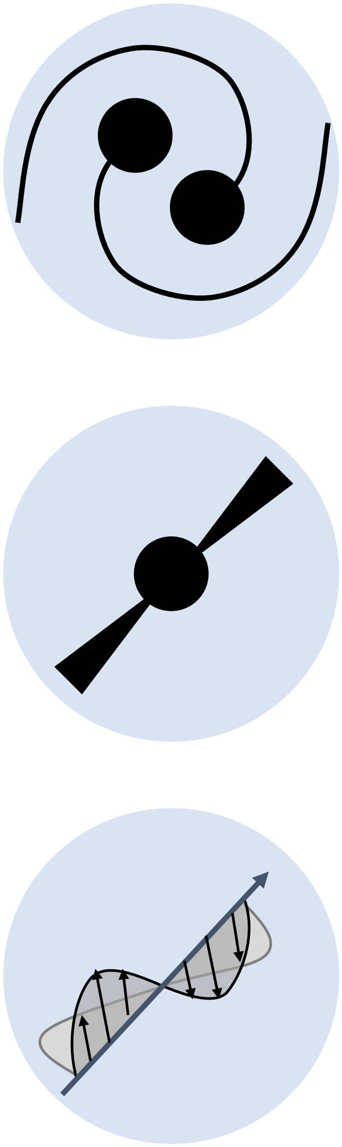
Bhalerao et al., 2024, ExA, 57, 24
https://arxiv.org/abs/2211.12055

Mission name	Energy range (keV)	Effective area (cm^2)	FoV Sky fraction	FoV (sr)	Range Mpc	Volume Mpc^3	Sensitivity (1-s, 5σ) erg cm^{-2} s^{-1}	Sensitivity (1-s, 5σ) ph cm^{-2} s^{-1}	Reference
Daksha (single)	20–200	1300	0.7	8.8	76	1.27×10^6	4×10^{-8}	0.6	This work
Daksha (two)	20–200	1700	1	12.6	76	1.81×10^6	4×10^{-8}	0.6	This work
Swift-BAT	15–150	1400	0.11	1.4	67	0.14×10^6	3×10^{-8}	0.5	(a)
Fermi-GBM	50–300	420	0.7	8.8	49	0.35×10^6	20×10^{-8}	0.5	(b)
GECAM-B	6–5000	480	0.7	8.8	65	0.81×10^6	9×10^{-8}	—	(c)
SVOM/ECLAIRs	4–150	400	0.16	2	70	0.23×10^6	4×10^{-8}	0.8	(d)
THESEUS/XGIS	2–30	500	0.16	2	45	0.06×10^6	1.7×10^{-8}	—	(e)
THESEUS/XGIS	30–150	500	0.16	2	58	0.12×10^6	5×10^{-8}	—	(e)
THESEUS/XGIS	150–1000	1000	0.5	6.2	20	0.02×10^6	45×10^{-8}	—	(e)

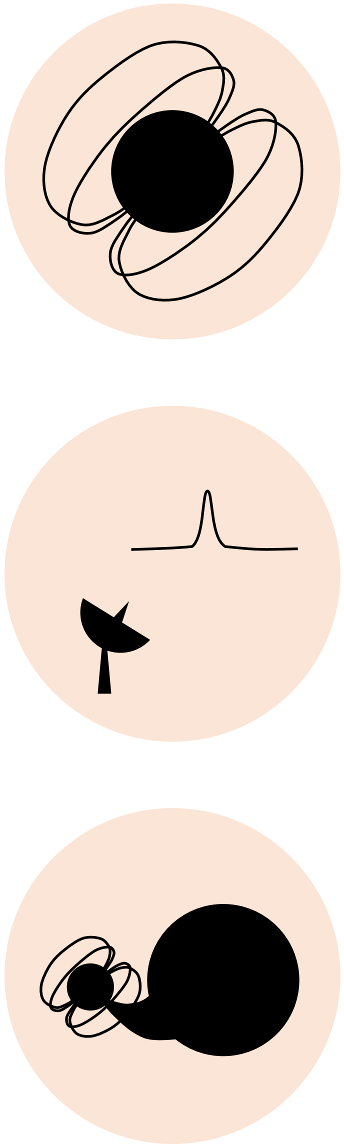
Daksha science

Bhalerao et al., 2024, ExA, 57, 23
https://arxiv.org/abs/2211.12052

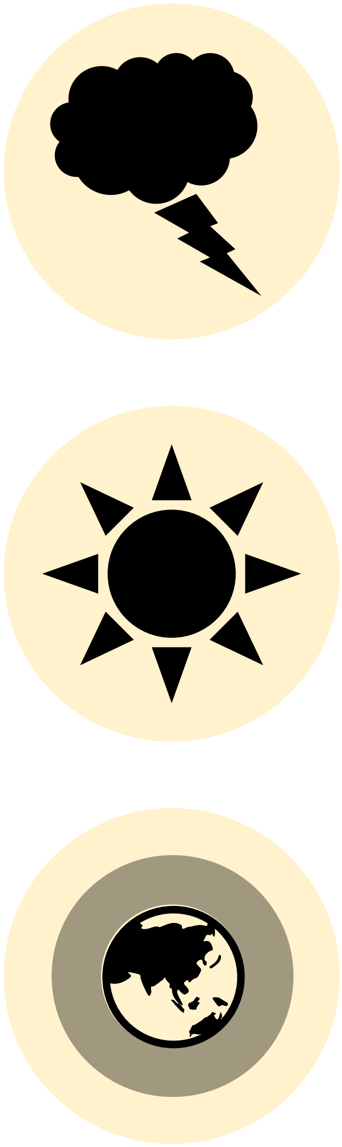
Relativistic Transients



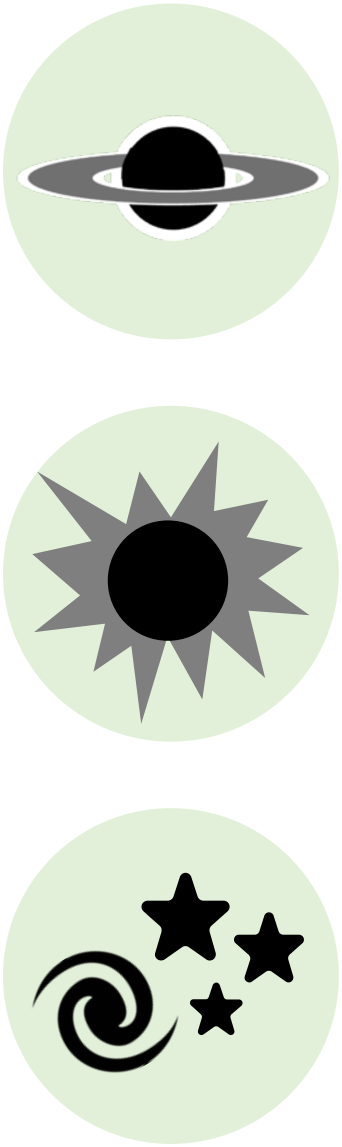
Compact Objects



Sun and Earth



Additional Science



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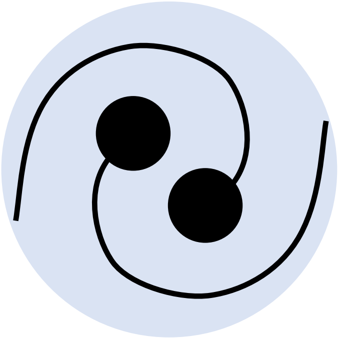
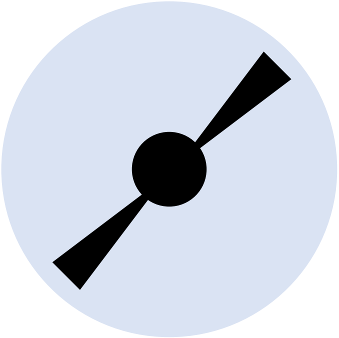


Electromagnetic Counterparts to Gravitational Wave Sources
Highest volumetric coverage among all satellites
Bhattacharjee, Banerjee et al., 2024, MNRAS, 528, 4255



Gamma Ray Bursts
Only satellite for soft prompt emission
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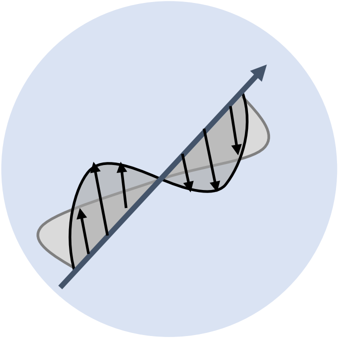

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More Neutron Star events

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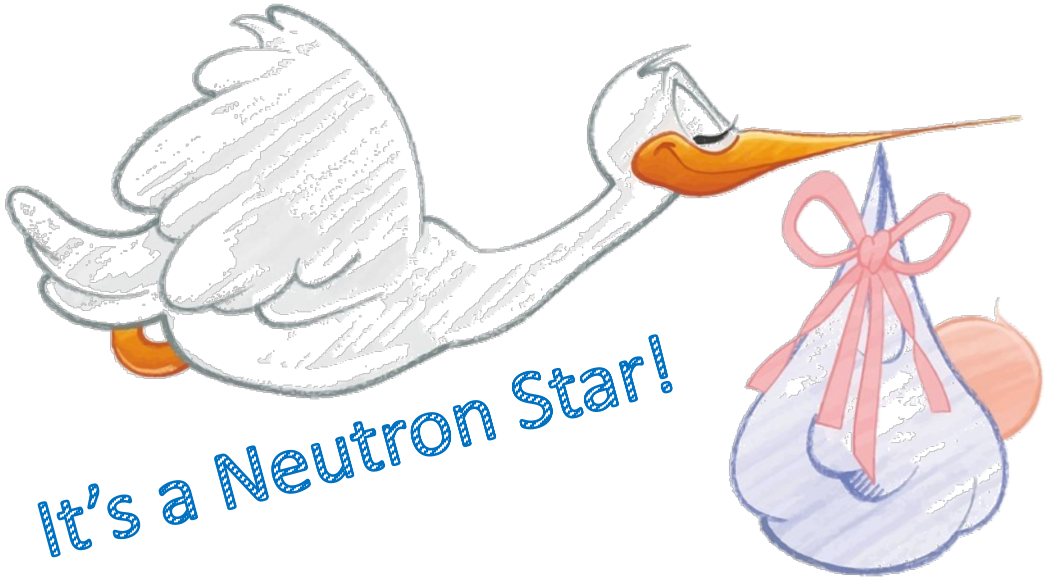

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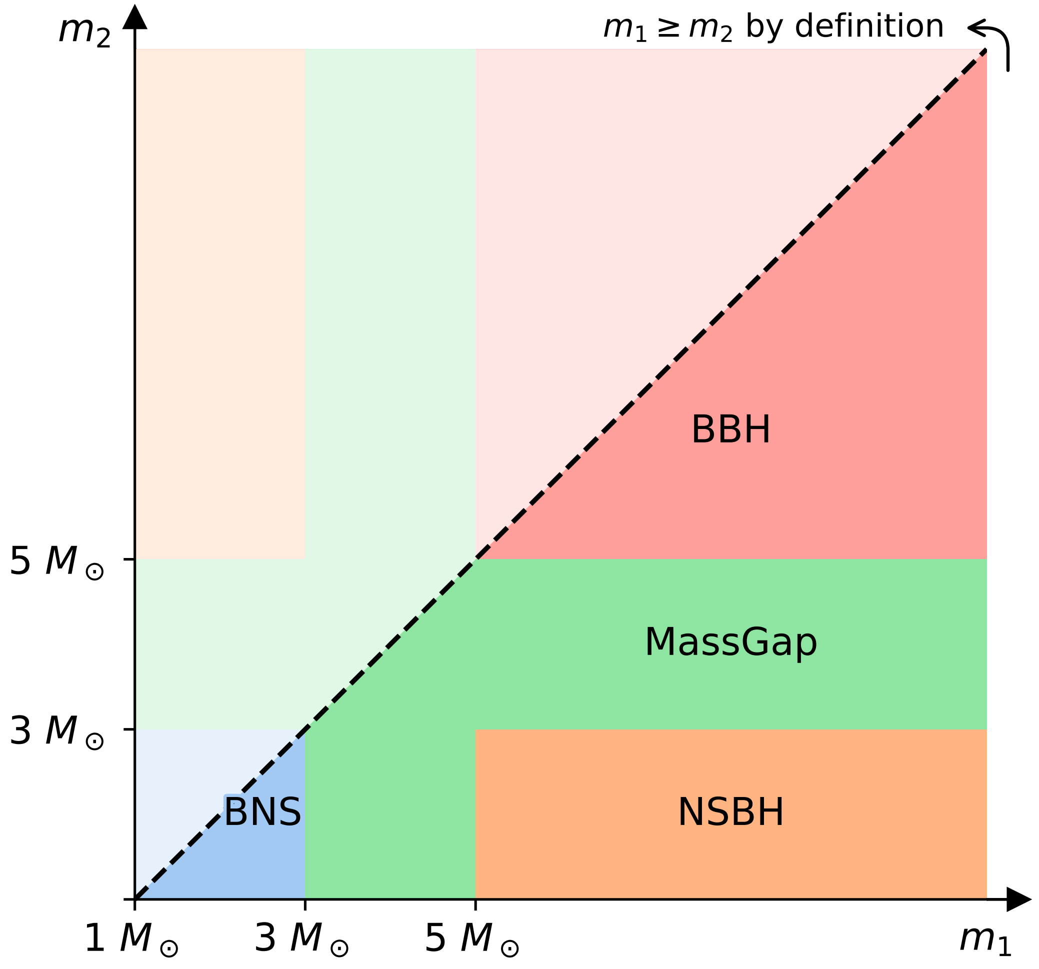

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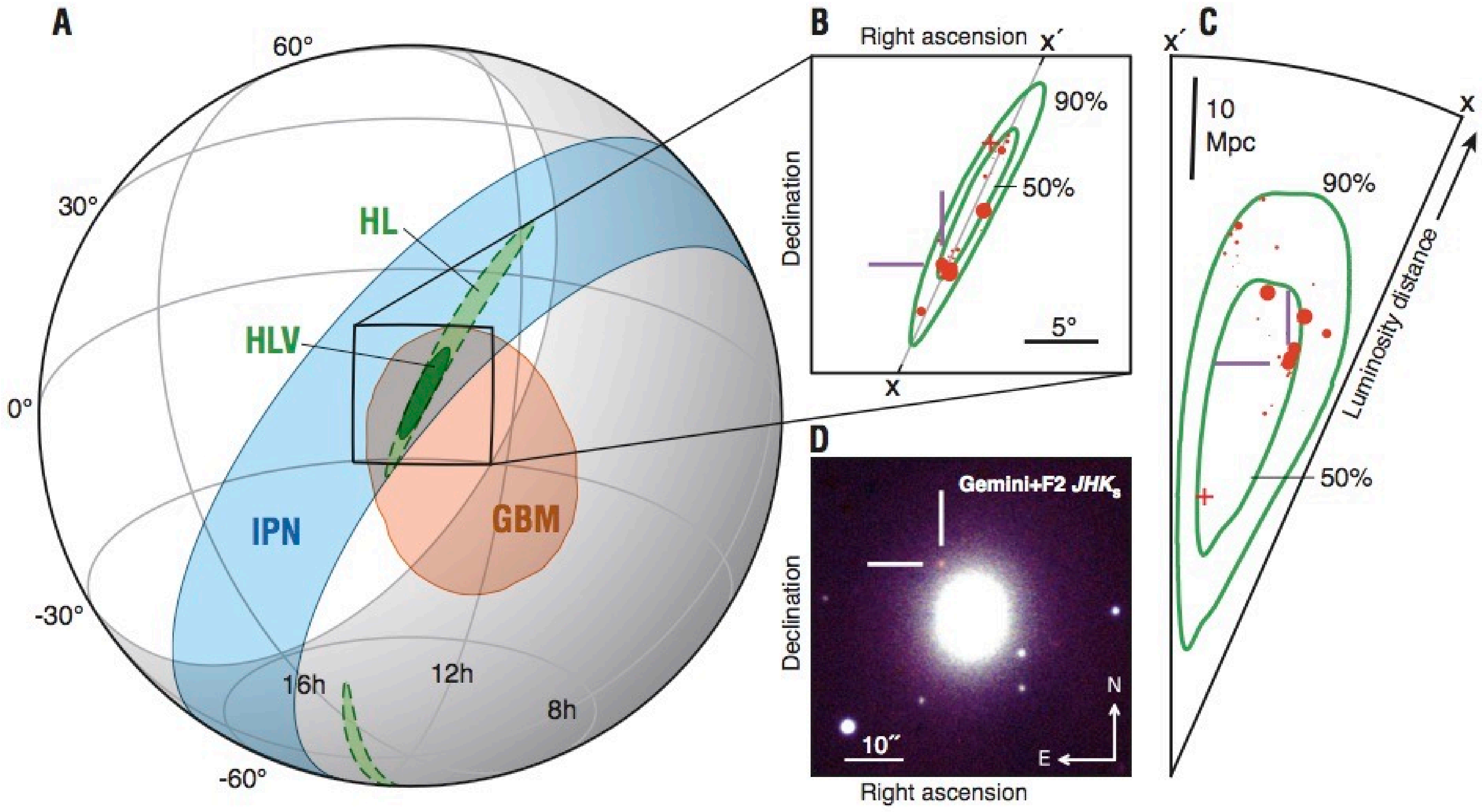
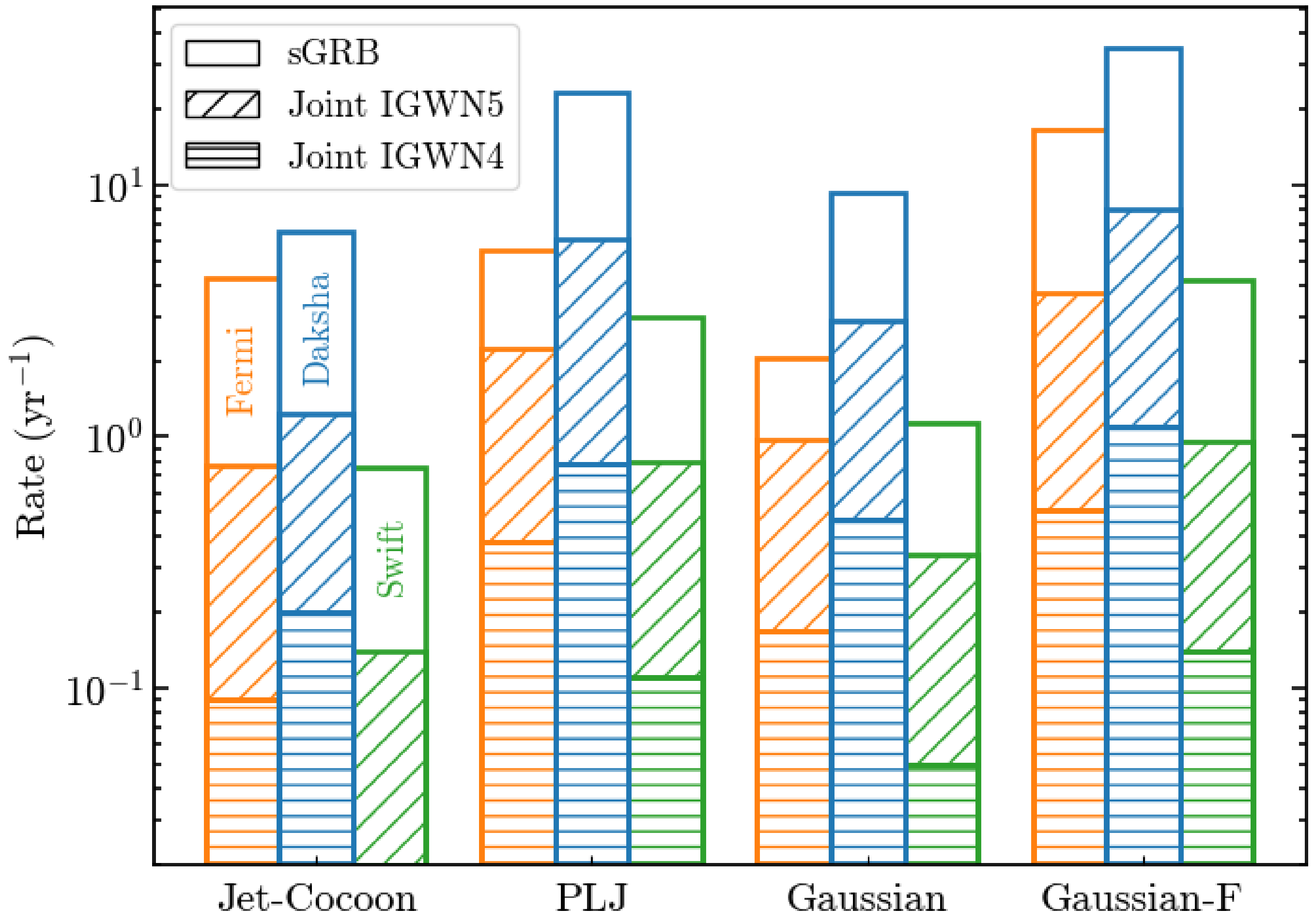


Limitation for all LEO satellites!

Daksha + EMGW

- Rates:
  ~ 10 events / year
- EMGW Range
  1–20/year
- Volumetric reach
  13x Swift
  5x Fermi GBM



Bhattacharjee, Banerjee et al., 2024, MNRAS, 528, 4255

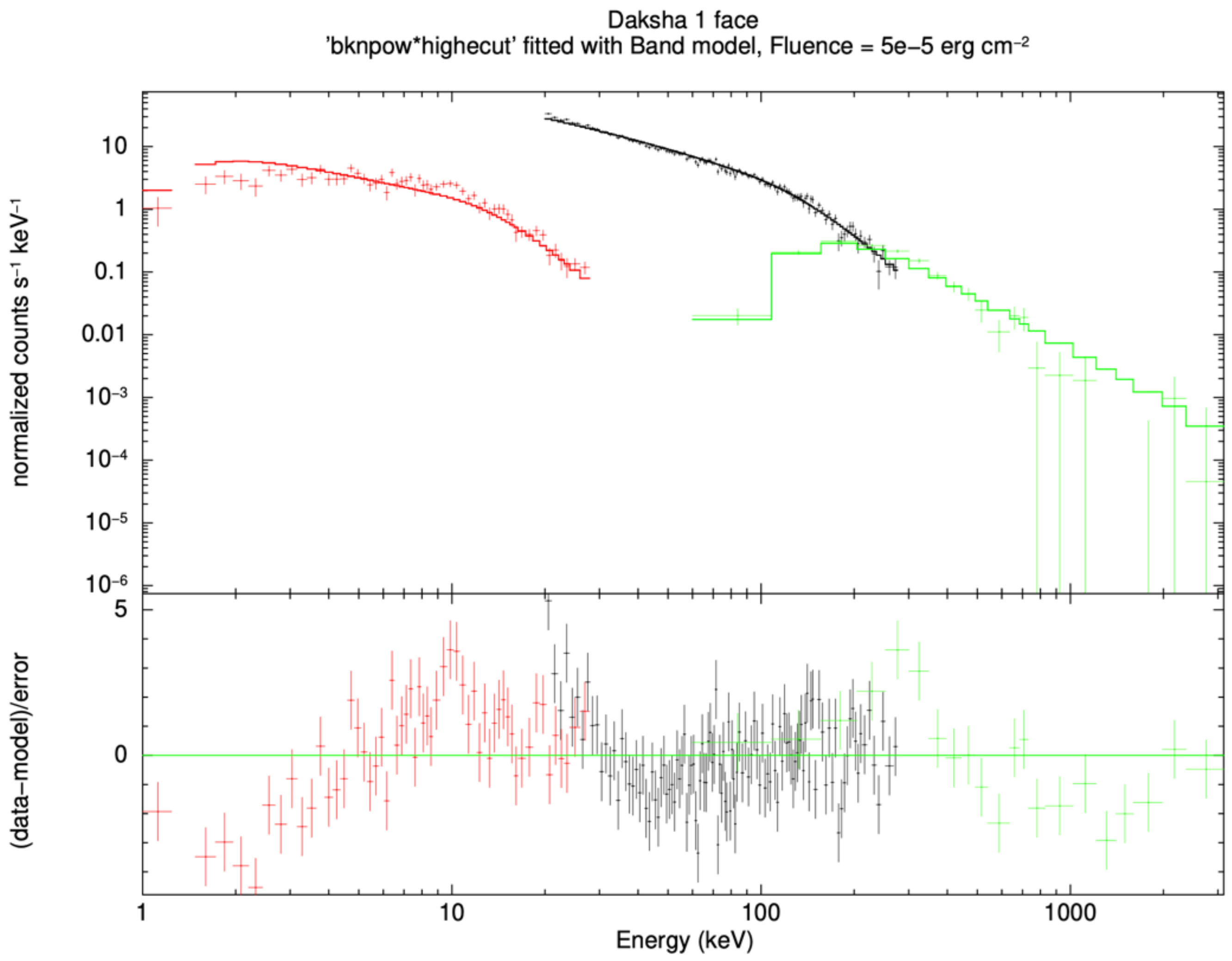
Subthreshold searches

- Threshold set by “all sky, all time” false alarm rate
- Direction + Time ⇒ search with lower FAR

Huge discovery space!

GRB spectroscopy

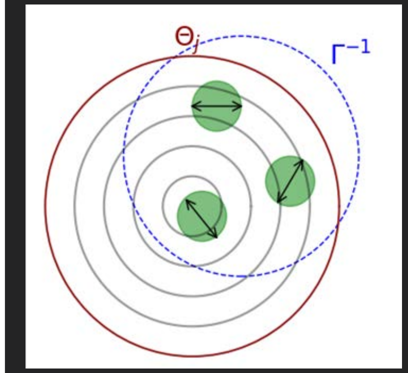
- Often modelled as “band function”
- Current data often not good enough for physical modelling
- Daksha can tell the difference!
  - Simulated spectrum: Broken power-law with high-energy cutoff
  - Fit: Band
  - Residuals clearly seen!

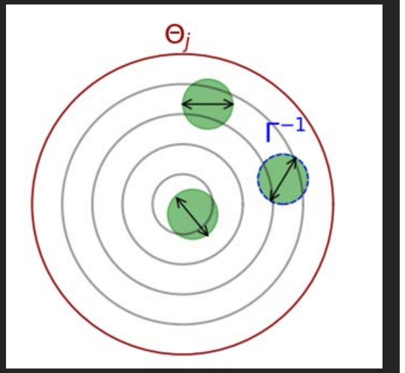


GRB Polarisation

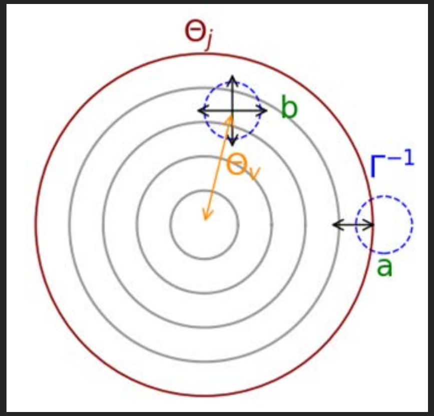
- Several GRB models consistent with current GRB data
- Key distinguishing factor: polarization!
- SO: synchrotron model with a globally ordered magnetic field
- SR: synchrotron model with a small-scale random magnetic field produced by shocks within jet
- CD: Compton drag model (Inverse Compton scattering of soft seed photons)

Other parameters





θ_J compared with Γ^{-1}



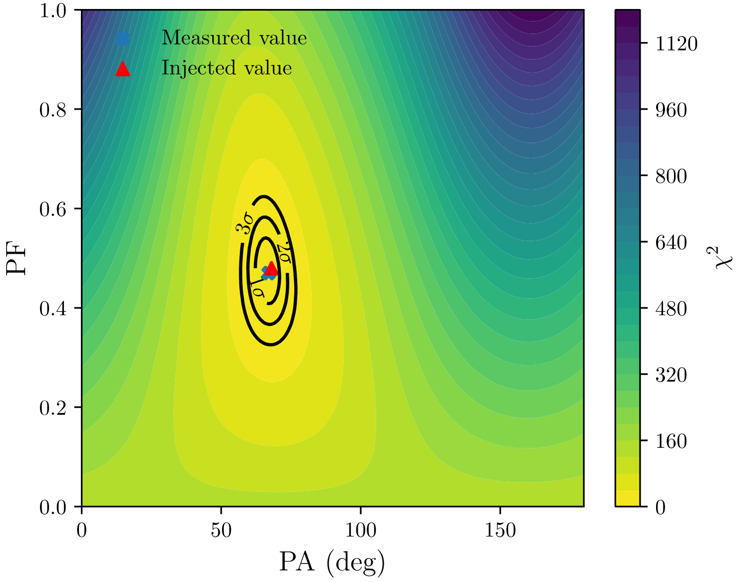
Viewing angle θ_V

Daksha to the rescue!

- Builds upon AstroSat CZTI success in polarisation
- GEANT4 mass models and simulations
- Expected:
  5 measurements/year

Simulations

GRB180914B



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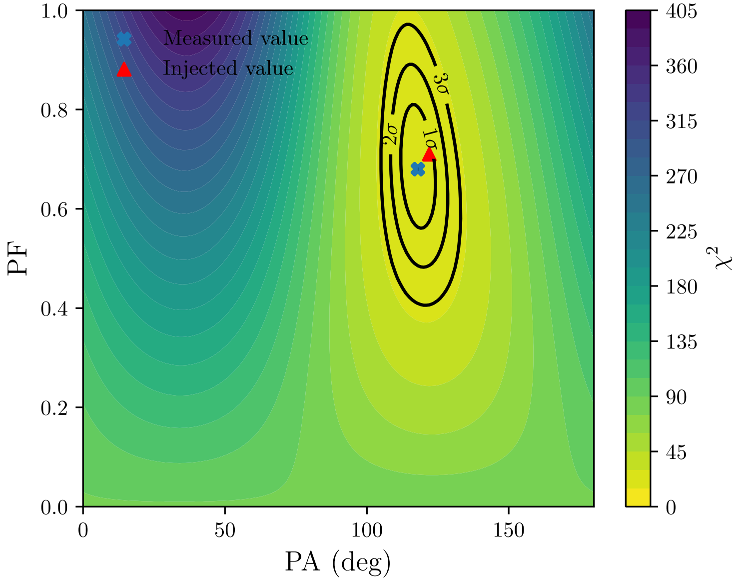

Published: Bala, Mate et al., 2023, JATIS, 9, 048002

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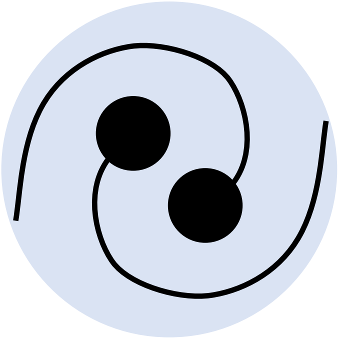

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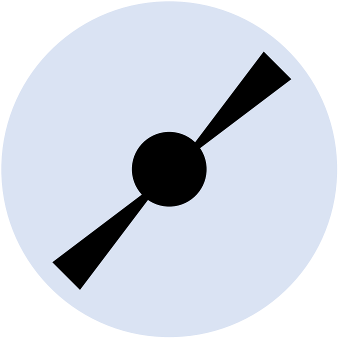

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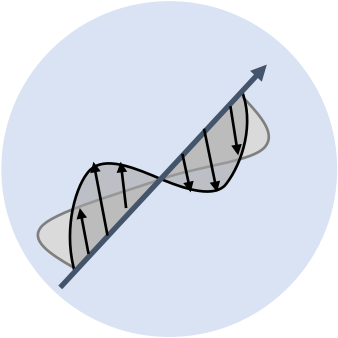

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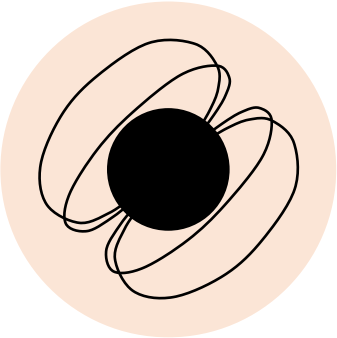
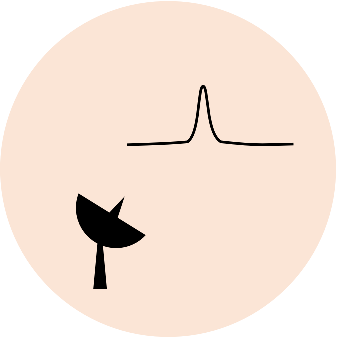


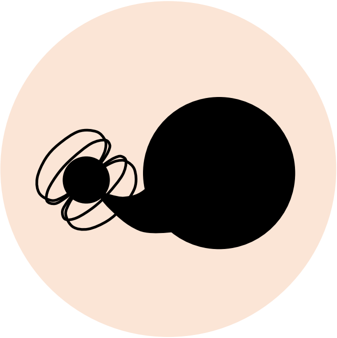
Magnetar flares, Soft Gamma Repeaters

Continuous monitoring for outbursts



Fast Radio Bursts and Counterparts

Highest sensitivity of all spacecraft!

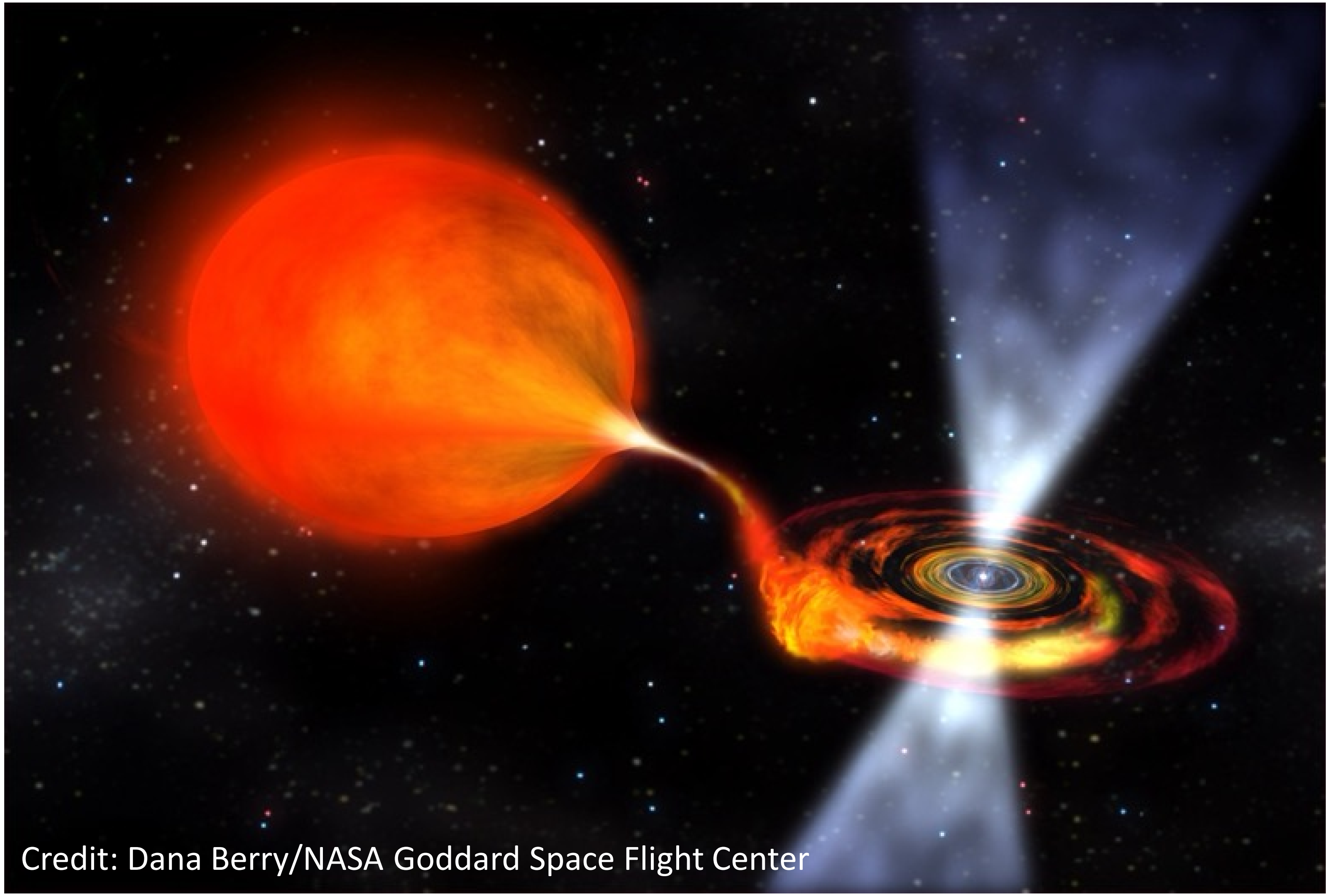


Accreting X-ray Pulsars

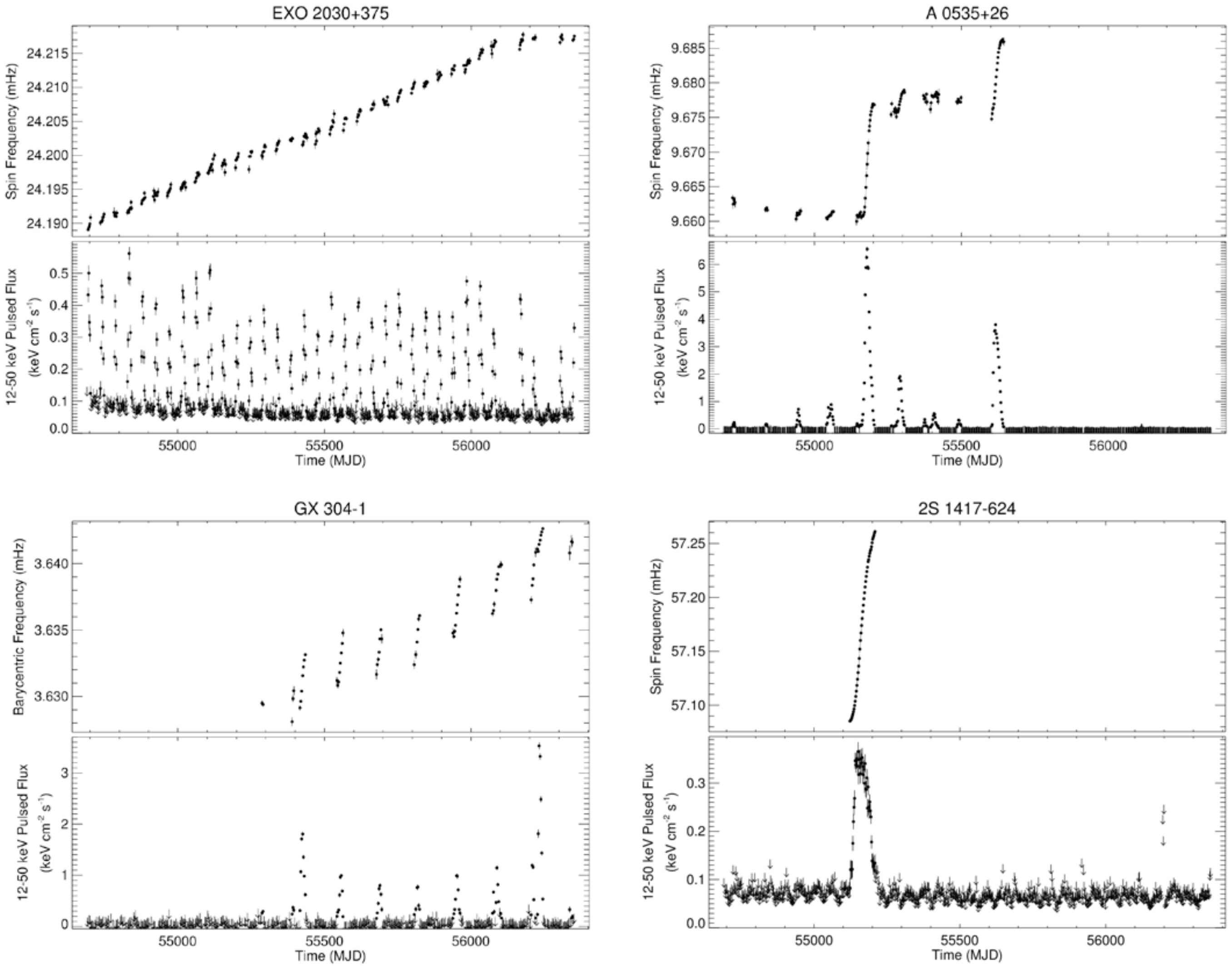
Better sensitivity than Fermi GBM, BATSE

Accreting X-ray pulsars

- High / Low mass X-ray binaries
- Neutron star accretes matter from companion
- Accretion → energy release → luminosity
- Accretion → angular momentum → spin change

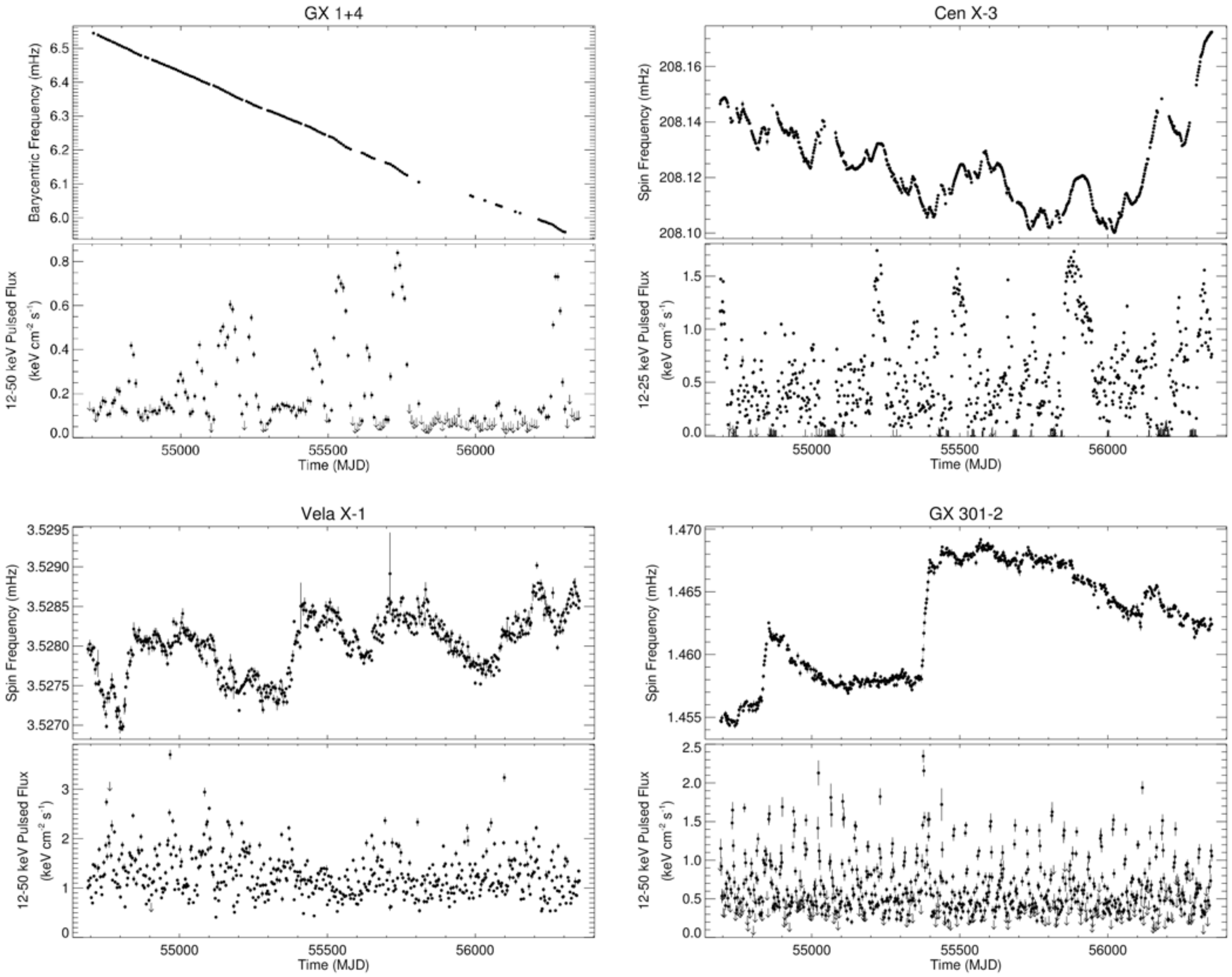

Credit: Dana Berry/NASA Goddard Space Flight Center

Transient Accreting X-ray Pulsars



- Accretion torque strongly correlated to luminosity
- Changes unpredictable: needs continuous monitoring
- (Data: Fermi GBM, CGRO / BATSE)
- Slide courtesy Biswajit Paul

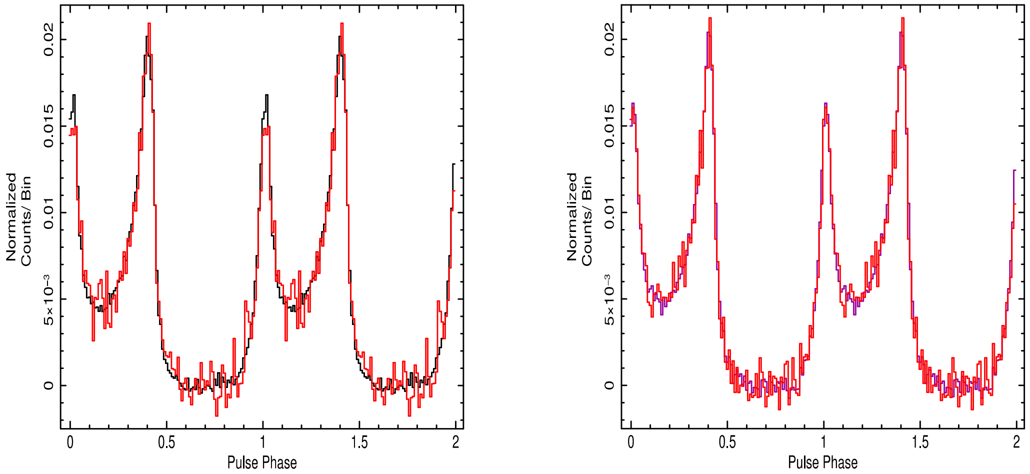
Persistent Accreting X-ray Pulsars



- Accretion torque weakly correlated to luminosity
- Changes unpredictable: needs continuous monitoring
- (Data: Fermi GBM, CGRO / BATSE)
- Slide courtesy Biswajit Paul

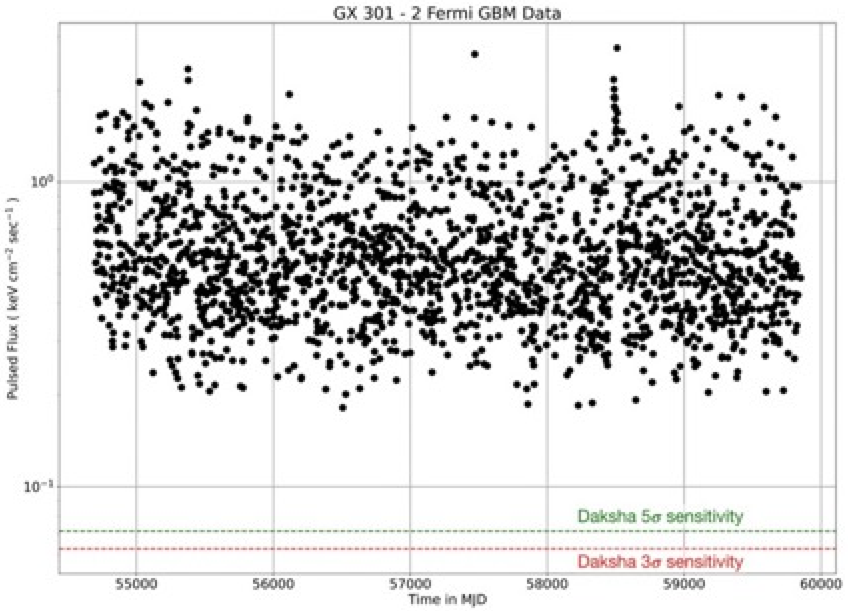
Monitoring pulsars

- Concept proven with AstroSat CZTI
- Anusree KG, et al 2022, JoAA, 43, 91



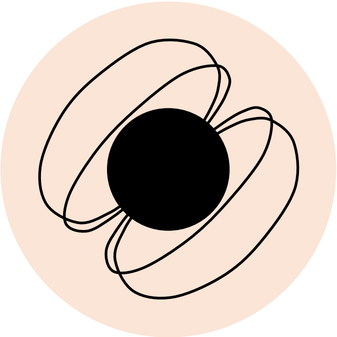
Crab Pulsar detected in on-axis data (left), and off-axis (right) data from CZTI

- Simulations extended to Daksha: continuous monitoring of all Fermi GBM pulsars and more!



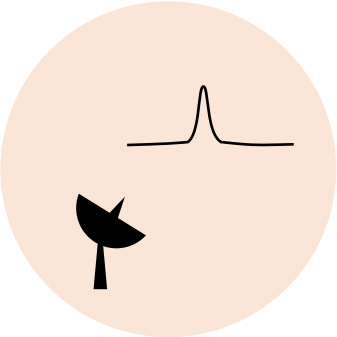
GX301-2 simulations for Daksha, based on Fermi GBM data.

Compact Objects



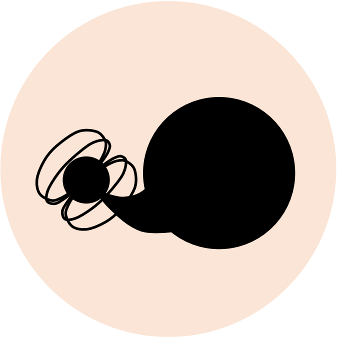
Magnetar flares, Soft Gamma Repeaters

Continuous monitoring for outbursts



Fast Radio Bursts and Counterparts

Highest sensitivity of all spacecraft!



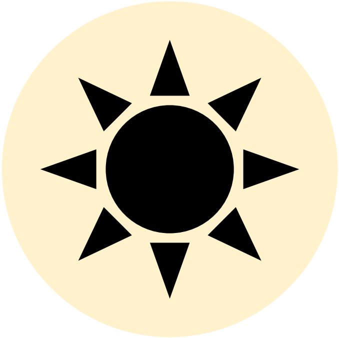
Accreting X-ray Pulsars

Better sensitivity than Fermi GBM, BATSE

Sun and Earth

Terrestrial Gamma Ray Flashes

Higher sensitivity than dedicated ISS/ASIM mission!



Solar Flares

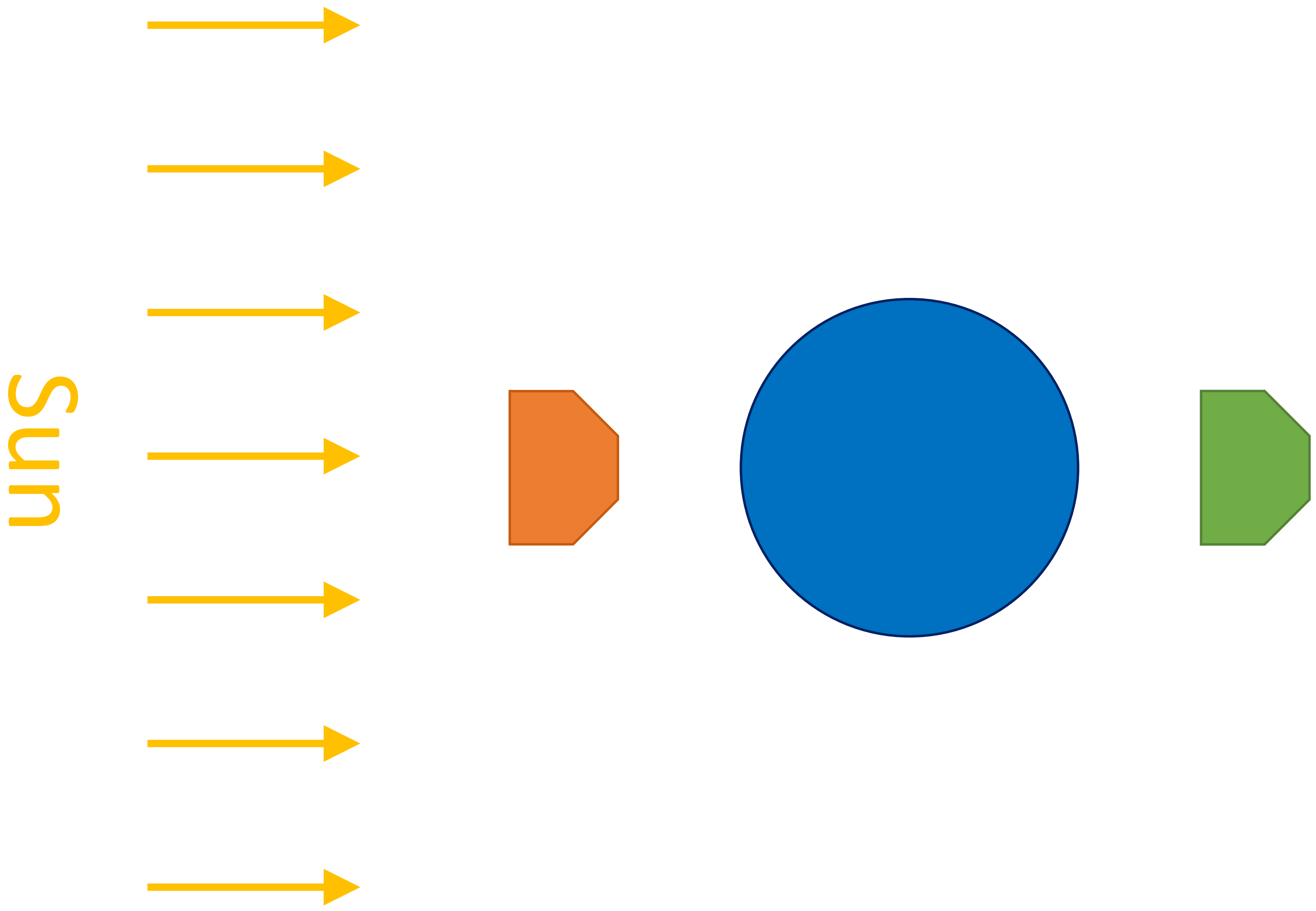
Higher sensitivity than RHESSI

Earth monitoring

Hard and soft X-ray monitoring of the atmosphere

Sun as a star: Hard X-ray studies

- Continuous monitoring of the Sun in hard X-rays (20 – 200 keV)
- Higher effective area than RHESSI
  - 1200 cm^2 for each satellite



Sun and Earth

Terrestrial Gamma Ray Flashes

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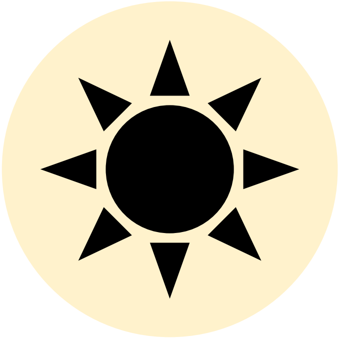


Solar Flares

Higher sensitivity than RHESSI

Earth monitoring

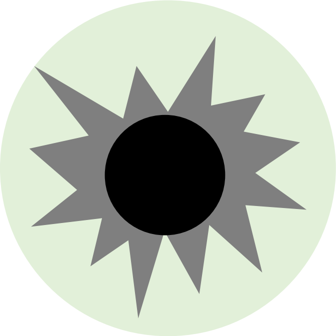
Hard and soft X-ray monitoring of the atmosphere

Additional Science

Primordial Black Holes (Cosmology)

Probing a mass range for the first time!

Gawade et al., 2024, MNRAS, 527, 3306



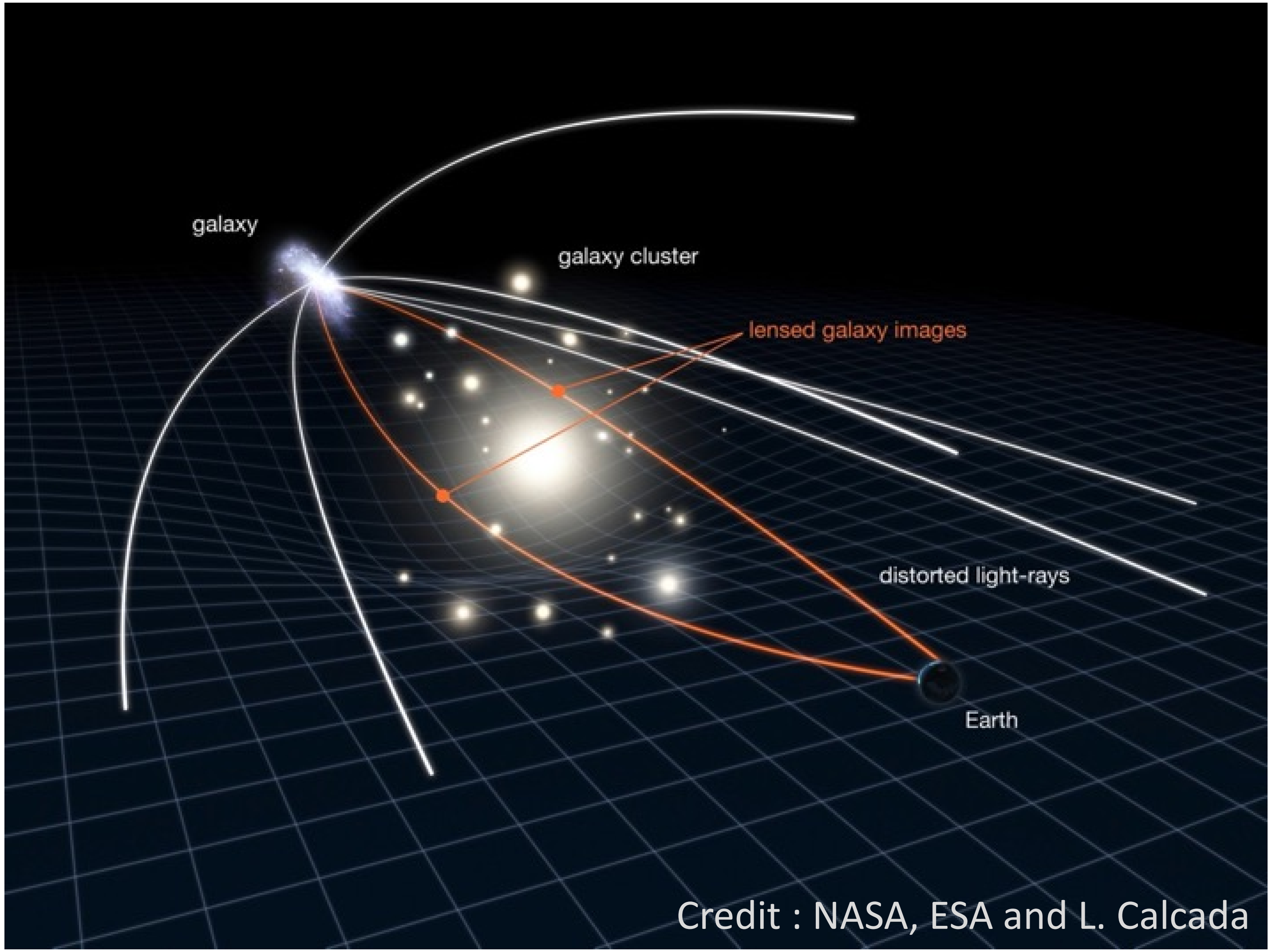
Novae and slow transients

Hard X-ray lightcurves of novae

Persistent sources

Daily lightcurves of persistent sources

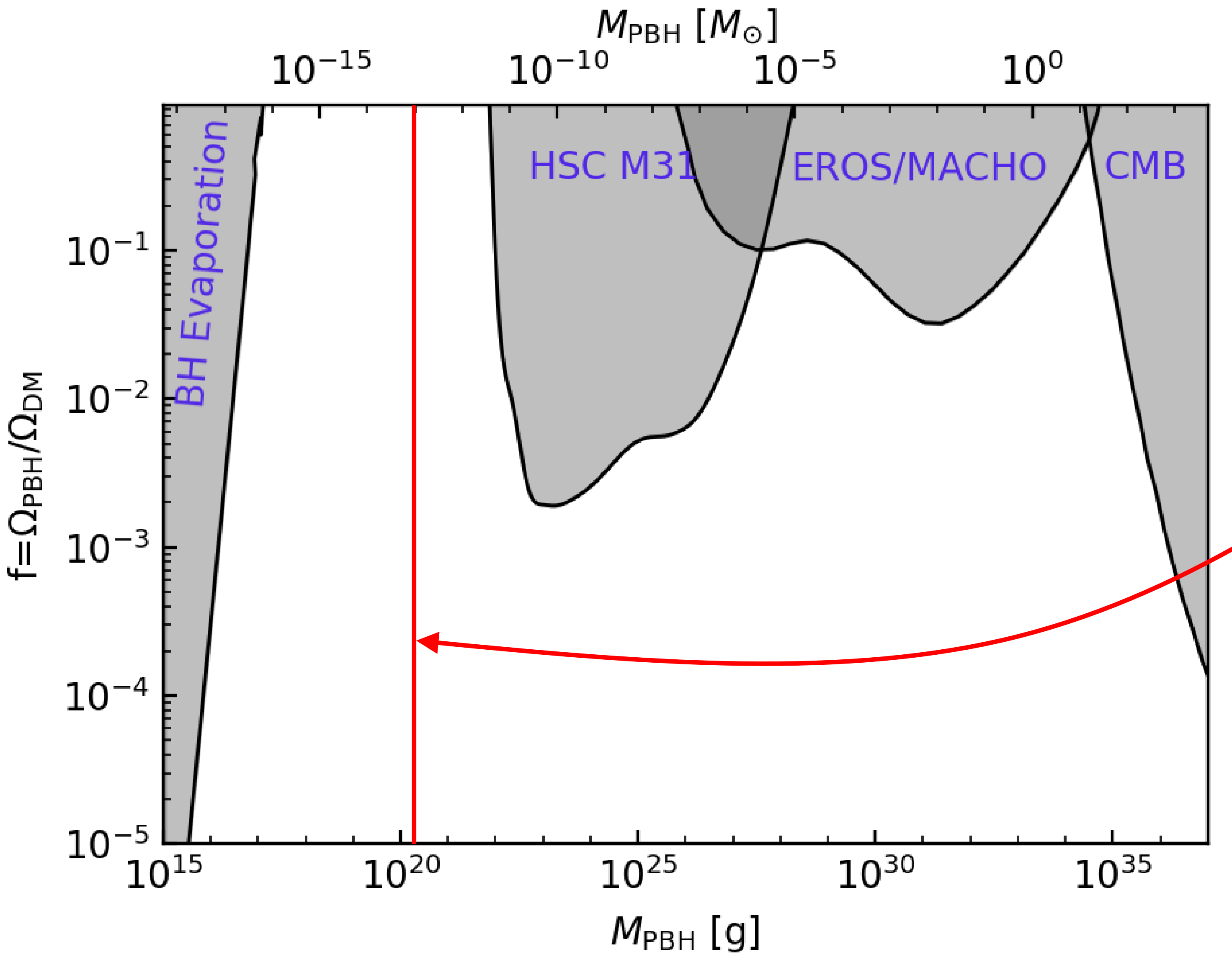
Gravitational Lensing



- Each "image" has a different magnification
- ⇒ each image has different intensity
- Intensity ratio depends on:
- Lens mass
- Angular offset

Based on slides by
Priyanka Gawade (IUCAA)

Primordial black holes

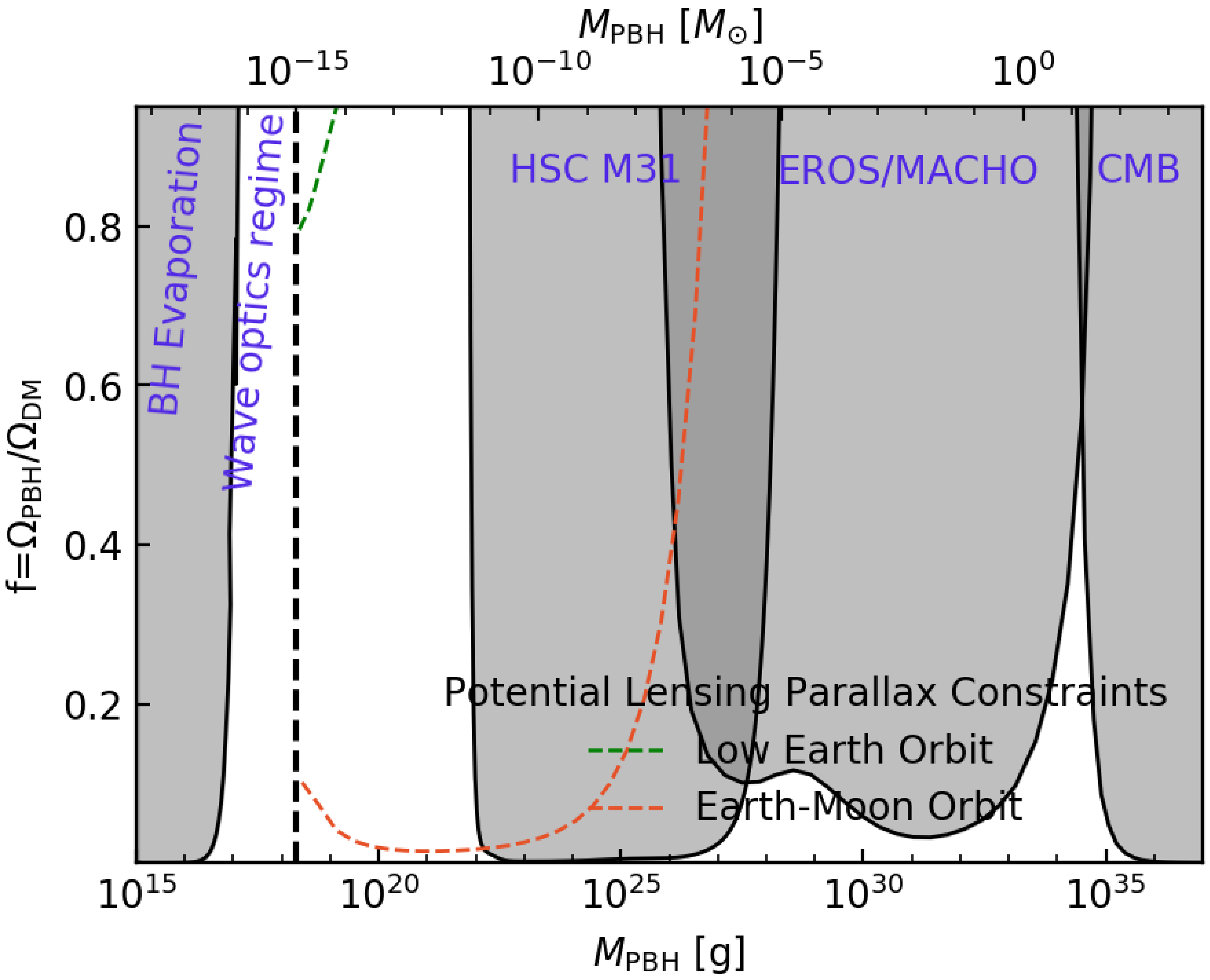


$$R_S = \frac{2GM}{c^2}$$

$$= 3\ \text{Å} \left(\frac{M}{10^{-13} M_\odot} \right)$$

λ (20 keV) = 0.6 Å

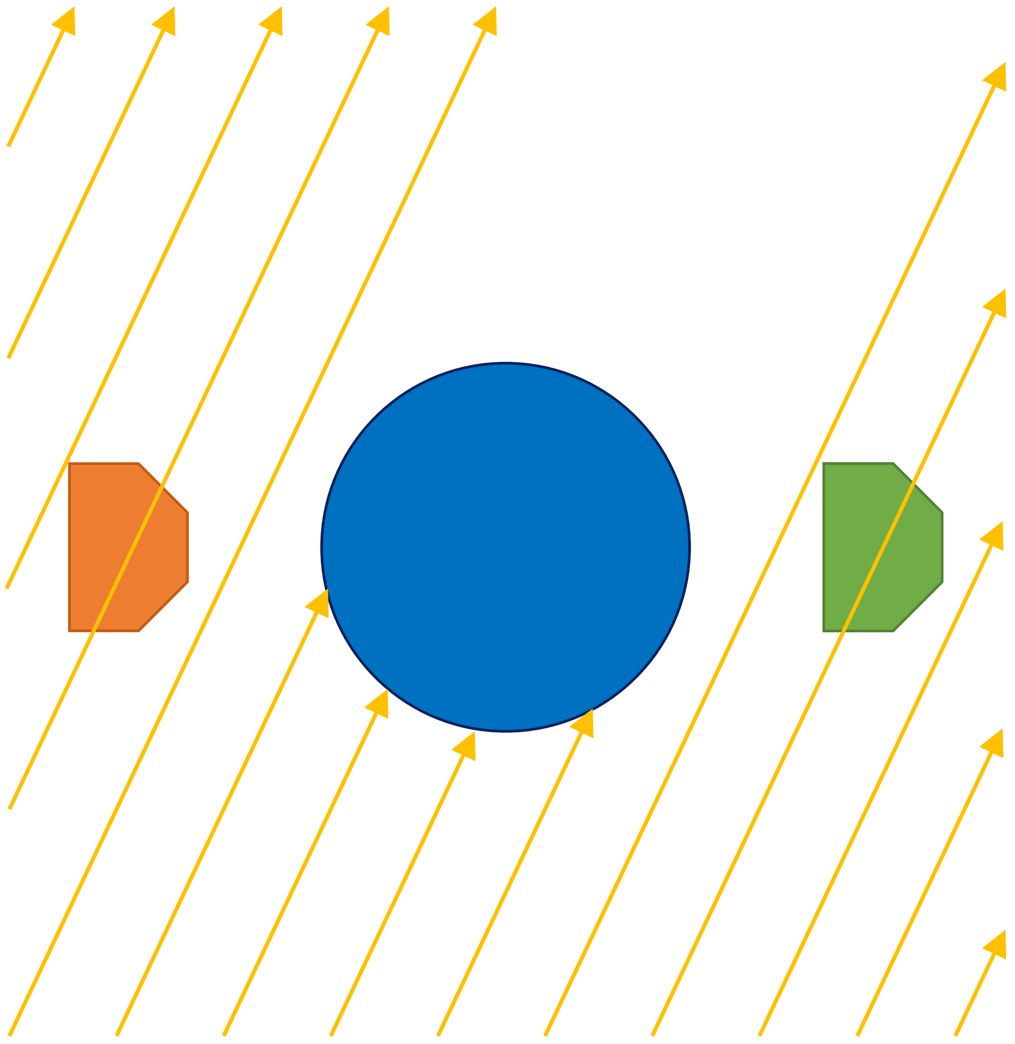
Probing Primordial Black Holes with Daksha



- Can probe the only remaining mass range, for the first time!
- If all dark matter made of PBHs, 50-80% chance of detecting an event with 10,000 GRBs
- Gawade, More & Bhalerao, MNRAS, 527, 2, pp.3306-3314

Earth Occultation Imaging

- Flux changes when crossing Earth shadow
- Each orbit:
  1 “Ingress”
  1 “Egress”
- Daily orbits: 14
- Measurements: 56 / day!

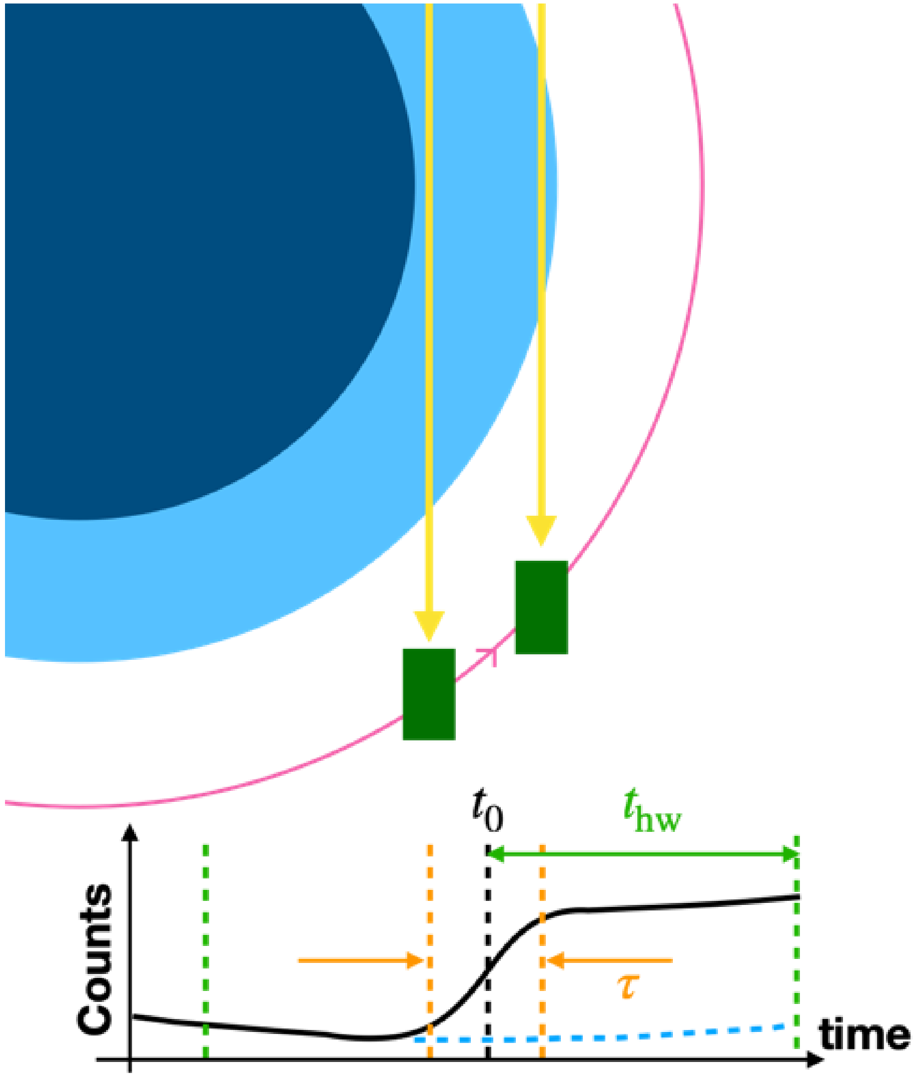


Demonstrated with CZTI

- CZTI as an all-sky monitor
- Measured fluxes of Crab, Cyg X-1

- Daksha has much higher effective area!

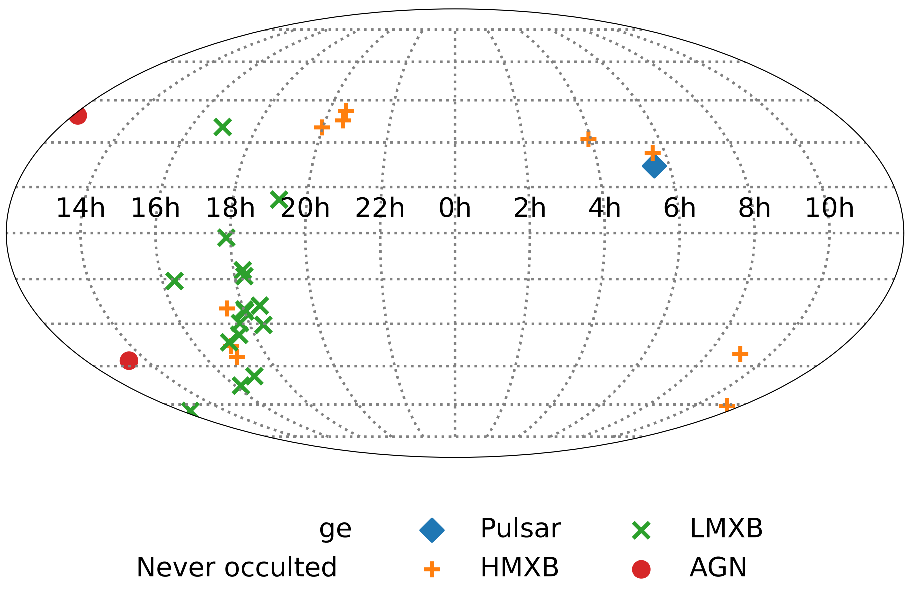
- Singhal et al, 2021, JoAA, Volume 42, Issue 2, article id.64



Slow transients

- Daksha direct detections: “fast” transients
  - Milliseconds – minutes
- “Slow” : anything that lasts for hours – days (or more!)
  - Binary outbursts
  - Novae, Supernovae
- Project underway: *How many BAT transients can Daksha detect?*
  - Anusree KG, Anirban Dutta, Judhajeet Basu, Vikram Rana, GC Anupama

Monitoring persistent sources



Sensitivity: 25 mCrab (daily)

~ 29 objects

- 1 Pulsar: **Crab**
- 2 AGN: Cen A, NGC 4151
- 10 HMXBs: **Cyg X-1**, Vela X-1, 4U 1700-377, Cyg X-3, 1A 0535+262, GX 1+4, OAO 1657-41, Cen X-3, EXO 2030+375, X Per

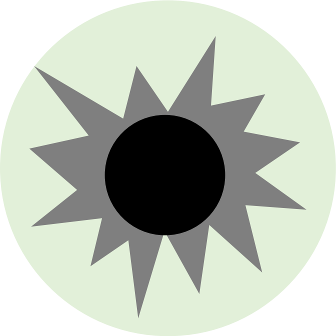
16 LMXBs: **Sco X-1, GRS 1915+105**, GX 301-2, 4U 1826-24, GRS 1758-258, SWIFT J1753.5-0127, 4U 1728-34, GX 17+2, Her X-1, 1E 1740.7-2942, GX 5-1, GX 349+2, 4U 1608-522, 4U 1812-12, 4U 1820-30, GX 339-4

Additional Science

Primordial Black Holes (Cosmology)

Probing a mass range for the first time!

Gawade et al., 2024, MNRAS, 527, 3306



Novae and slow transients

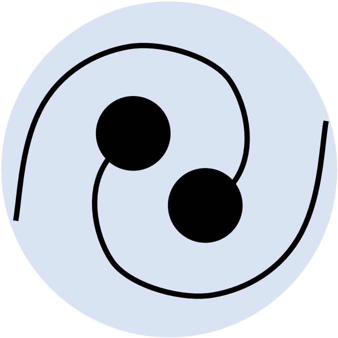
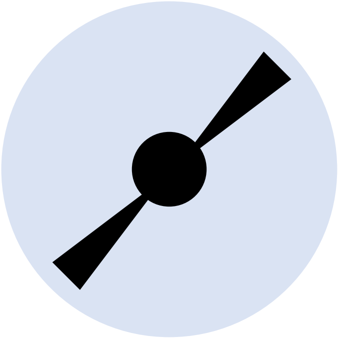
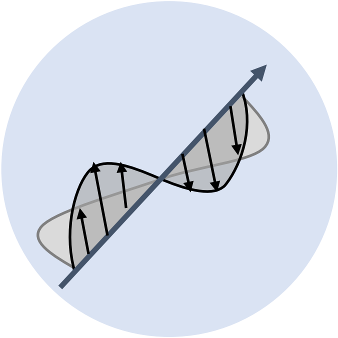
Hard X-ray lightcurves of novae

Persistent sources

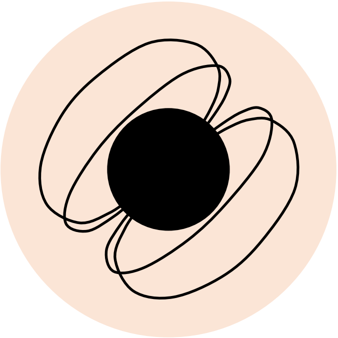
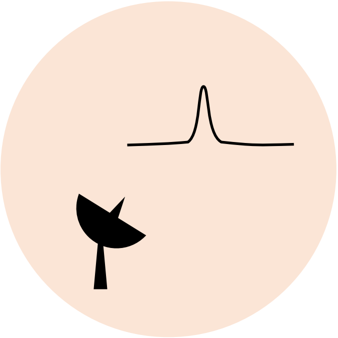
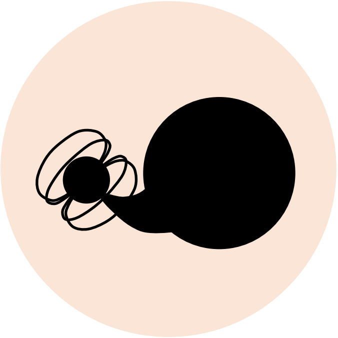
Daily lightcurves of persistent sources

Daksha science

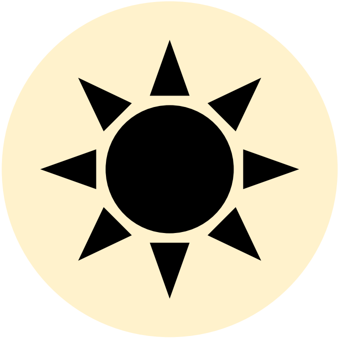
Relativistic Transients

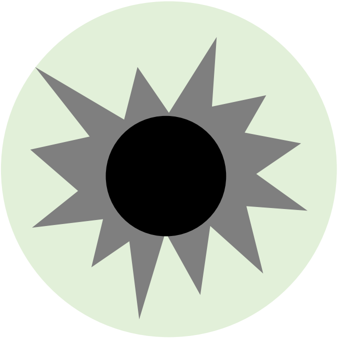
Compact Objects

Sun and Earth

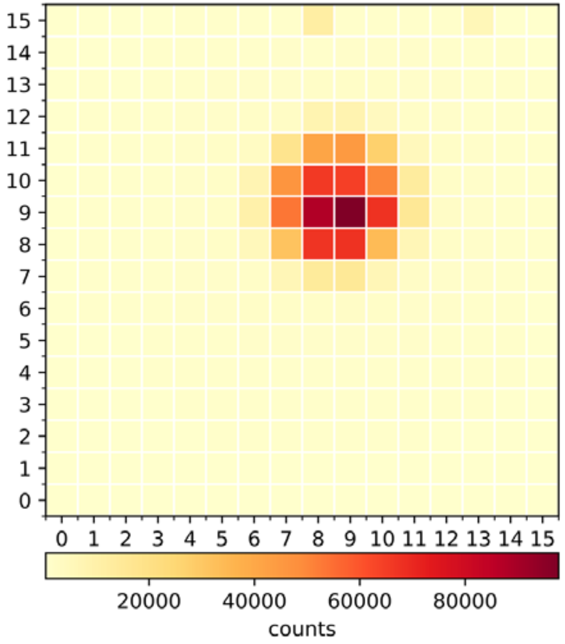

Additional Science

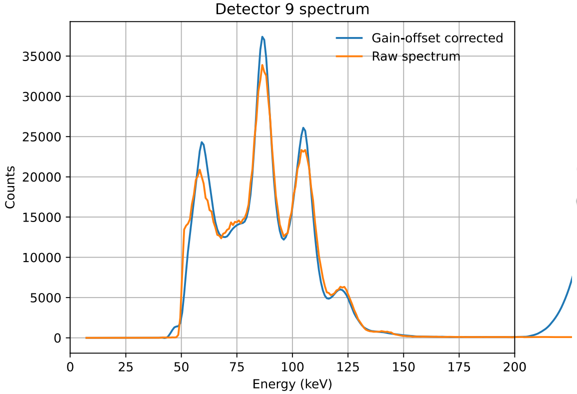

Lab results & status

Laboratory models of Medium energy, Low energy and high energy detectors packages have been built and tested.

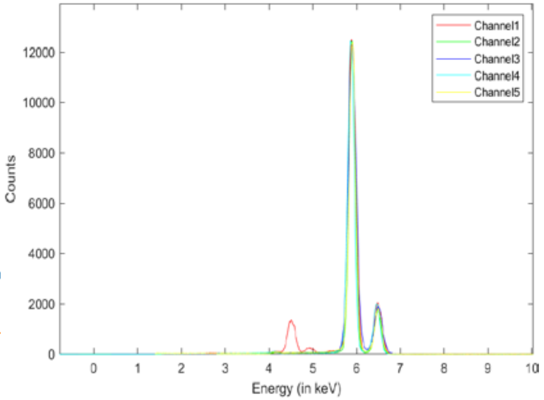
ME lab model: data with Am241 point source on one detector



ME: ~10% Energy resolution at 60 keV (room temperature), better than AstroSat CZTI



LE: Fe-source + Ti foil: 4.5 keV and 4.9 keV lines

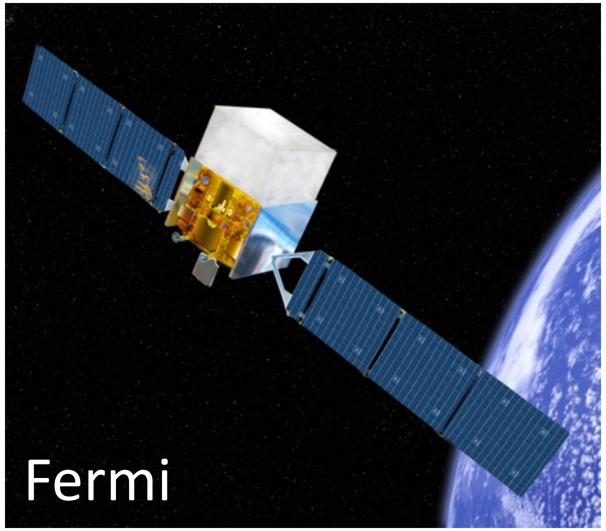


Daksha – Indian Eyes on Transient Skies

Daksha

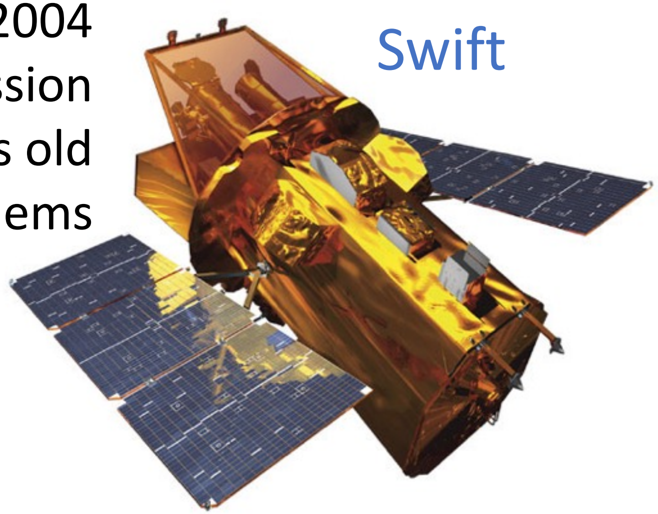
dakshasat.in

Current Global Fleet: Leaders

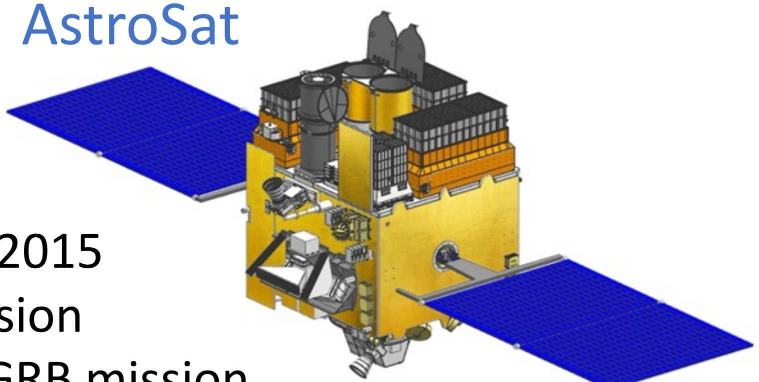


Launched 2008
5-10 year mission
Now 16 years old

Launched 2004
2+ year mission
Now 19 years old
Increasing problems



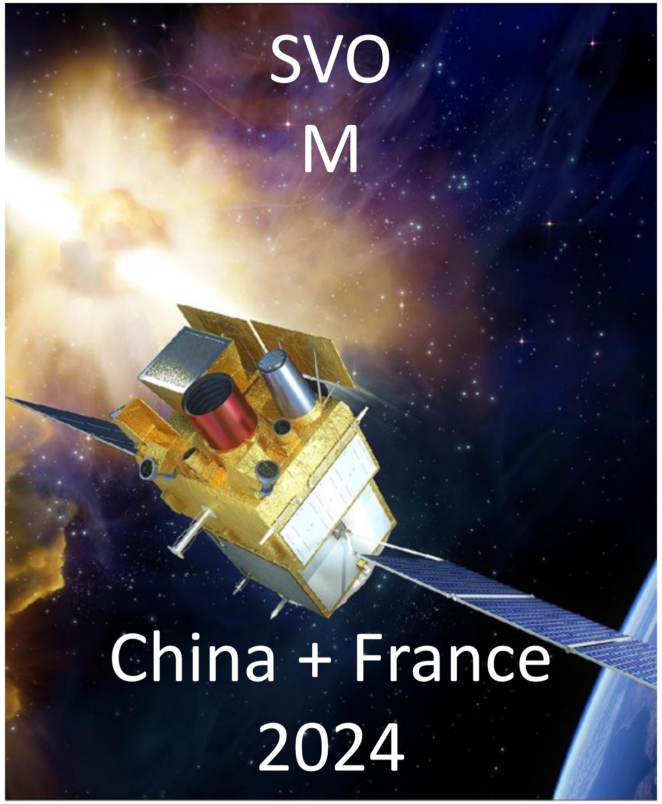
Launched 2002
5 year mission
End of science operations
on 31 December 2024

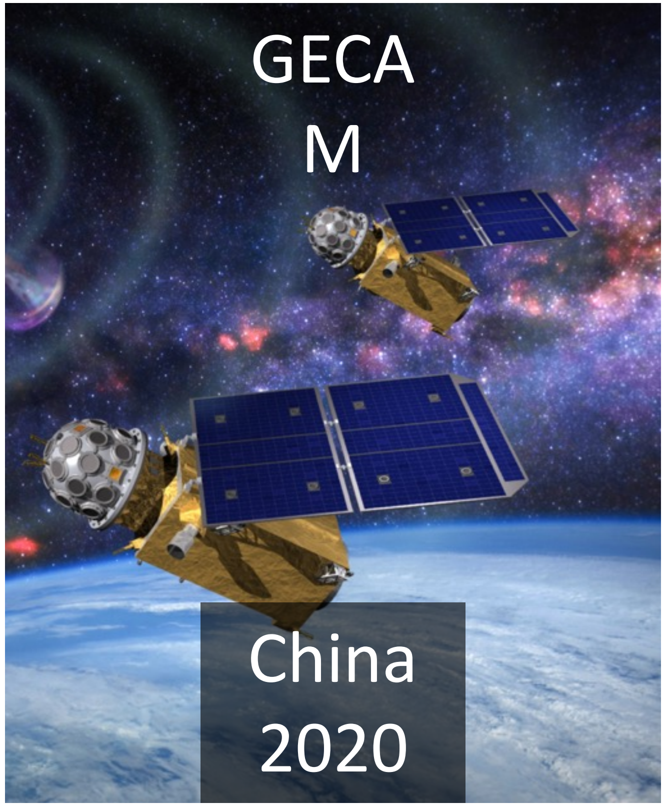


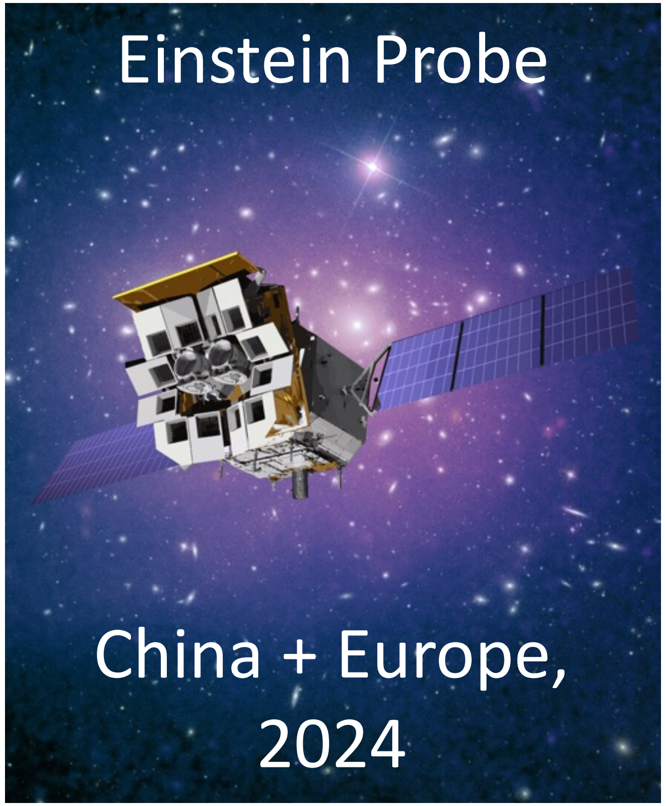
Launched 2015
5 year mission
Youngest GRB mission,
though not designed for GRBs!

Recent time-domain missions

- Less sensitivity and coverage than Daksha







Daksha

Indian Eyes on Transient Skies!

For more details, visit **dakshasat**.in

Science: At a Glance

Relativistic transients

- EMGW
- GRB – Fine time-resolved studies
- GRB – Soft X-ray spectra
- GRB polarization

Compact Objects

- Magnetars / SGRs
- Fast Radio Burst counterparts
- Accreting X-ray pulsars

Sun and Earth

- Terrestrial Gamma-ray Flashes
- Solar Flares
- Atmospheric X-ray fluorescence

Additional Science

- Primordial black holes
- Novae and slow transients
- Persistent sources

5 Refereed papers

Refereed publications

- “Daksha: On Alert for High Energy Transients”, (Main mission paper) Bhalerao et al., 2024, ExA, 57, 24
- “Science with the Daksha High Energy Transients Mission”, (Science paper) Bhalerao et al., 2024, ExA, 57, 23
- “Prospects of measuring Gamma-ray Burst Polarisation with the Daksha mission”, Bala, Mate, et al., 2023, JATIS, 9, 4
- “On the feasibility of primordial black hole abundance constraints using lensing parallax of GRBs”, Gawade et al., 2023, MNRAS, 527, 2
- “Joint gravitational wave-short GRB detection of Binary Neutron Star mergers with existing and future facilities”, Bhattacharjee et al., 2024, MNRAS, 528, 3

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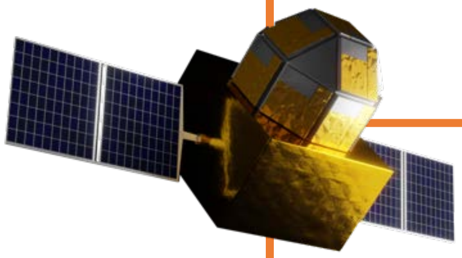
Synergies



	India	International
High Energy	AstroSat	Fermi, Swift, MoonCat...
Optical	GROWTH-India Rubin (LSST)	ZTF, GRANDMA Rubin (LSST)
Radio	uGMRT SKA	CHIME, LOFAR SKA
Solar	Aditya-L1 Chandrayaan XSM	STIX...
GW	LIGO-India	LIGO, Virgo, KAGRA

Daksha – broader impact

Astrophysics breakthroughs

- EMGW studies
- Cosmology and Hubble tension
- Primordial Black Holes

Prioritised by

- SSRF – SG1 (A&A)
- SSRF – SG2 (Gravity)
- ASI Vision Document
- Mega-Science Vision 2035 (PSA)

Broader impact

- Space Weather
- Atmospheric studies (TGFs, Fluorescence)
- LIGO-India (DST+DAE)
- Solar Physics

Daksha: Community

- Nationwide interest
- **Recommended** in various reports:
  - "Indian Astronomy in the Global Context – A Vision Document", Astronomical Society of India, 2024
  - "Mega-Science Vision 2035 – Astronomy and Astrophysics", Office of the Principal Scientific Advisor to the Government of India, 2024
- Also aligns with various international demands

Core team – faculty


Varun
Bhalerao
IITB Physics


Dipankar
Bhattacharya
Ashoka


Gulab
Dewangan
IUCAA


P J
Guruprasad
IITB Aero


Salil
Kulkarni
IITB Mech


Suddhasatta
Mahapatra
IITB Physics


Deepak
Marla
IITB Aero


Rakesh
Mote
IITB Mech


Archana
Pai
IITB Physics


Biswajit
Paul
RRI


Prabhu
Ramchandran
IITB Aero


Vikram
Rana
RRI


Siddharth
Tallur
IITB Elec


Santosh
Vadawale
PRL

+ Staff, Engineers, Students

Science: Glimpses of user community

Relativistic transients

- VB, DB, SVV, AP, L. Resmi (IIST), Shabnam Iyyani (IISER TVM), Kuntal Misra (ARIES), K.G. Arun (CMI), Kunal Mooley (IITK), Nirmal Raj (IISc), Suvodip Mukherjee (TIFR)…

Compact Objects

- BP (RRI), Manoneeta Chakraborty (IITI), MC Ramadevi (URSC)…

Sun and Earth

- SVV, Dibyendu Nandi (IISER Kol), Sankar (URSC)…
- Shyama Narendranath (URSC), Ankush Bhaskar (VSSC), Vishal Dixit (IITB)…

Additional Science

- VR, VB, Surhud More (IUCAA), G C Anupama (IIA), D K Sahu (IIA)…

International Scenario – Huge Interest !

Researchers who signed up as interested in Daksha Science

Daksha – Indian Eyes on Transient Skies

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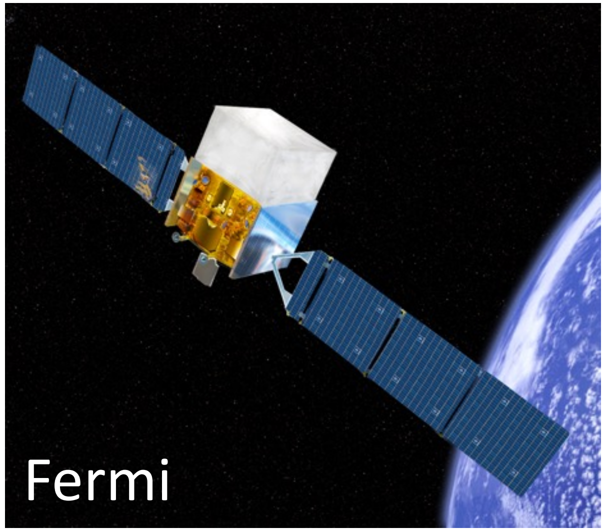
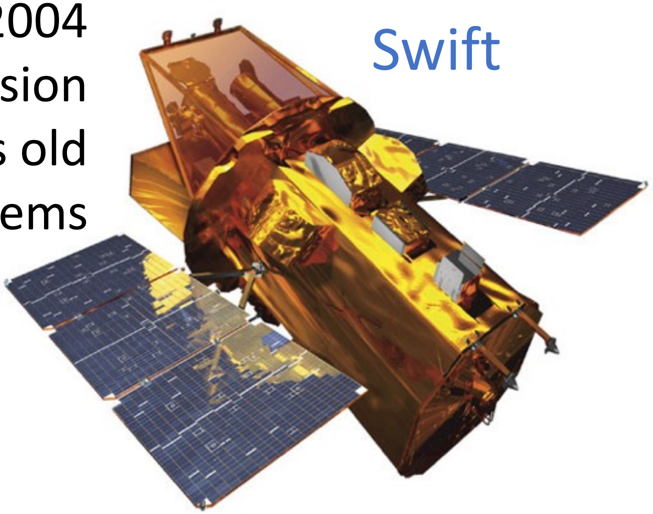
Current Global Fleet: Leaders



Launched 2008
5-10 year mission
Now 16 years old

Launched 2004
2+ year mission
Now 19 years old
Increasing problems

Swift



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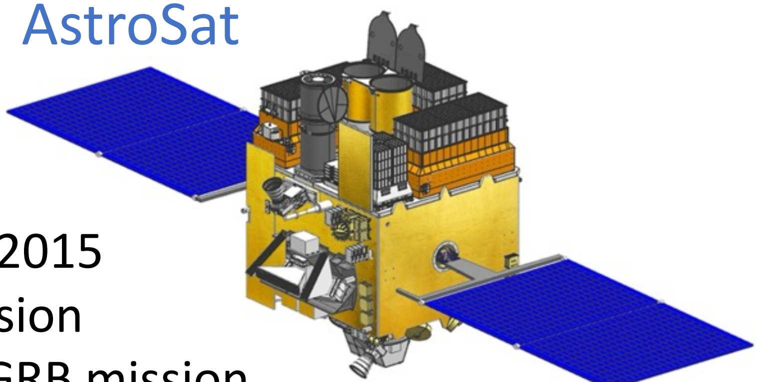
AstroSat



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5 year mission
Youngest GRB mission,
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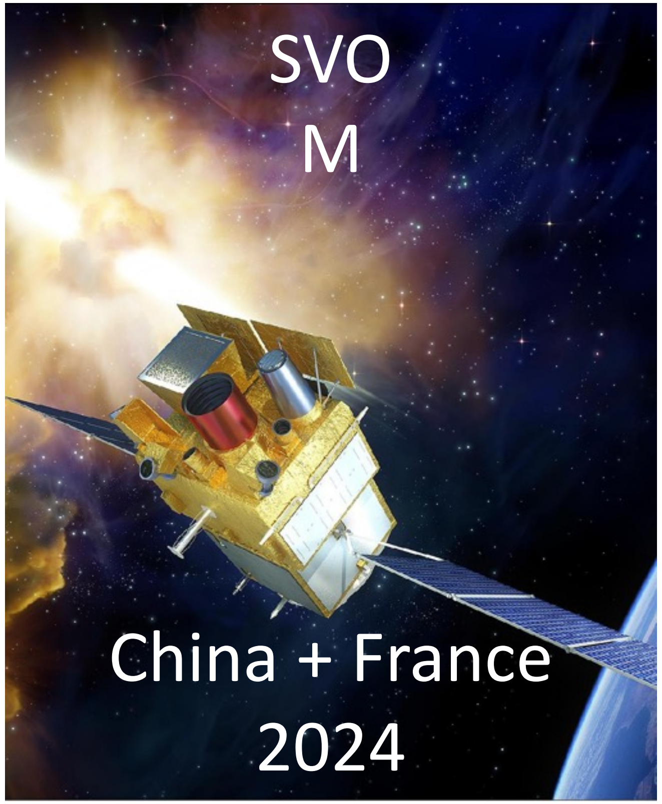
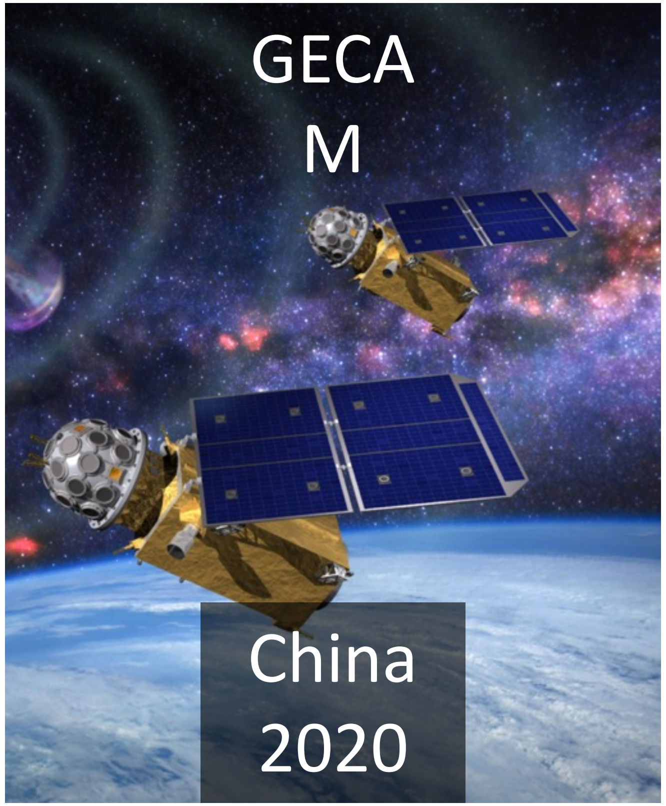
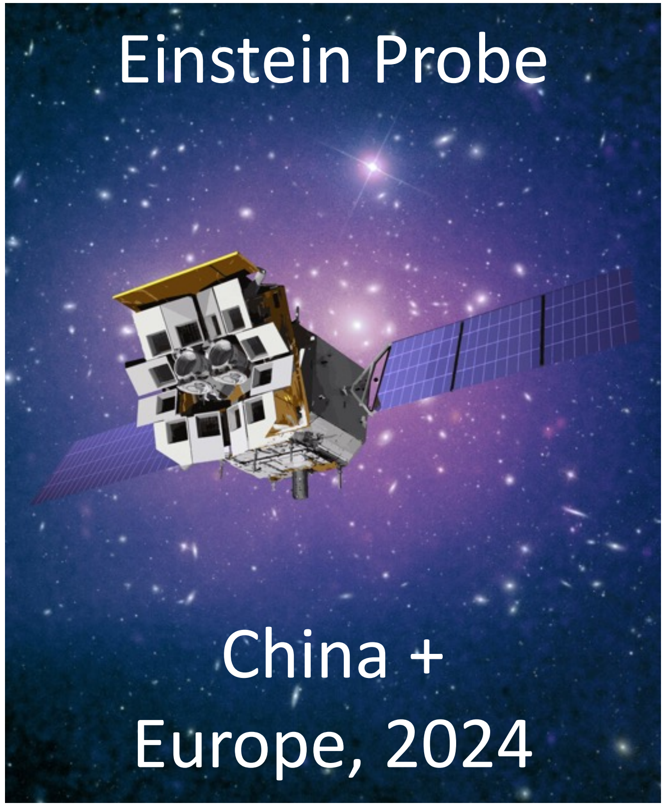
Recent time-domain missions

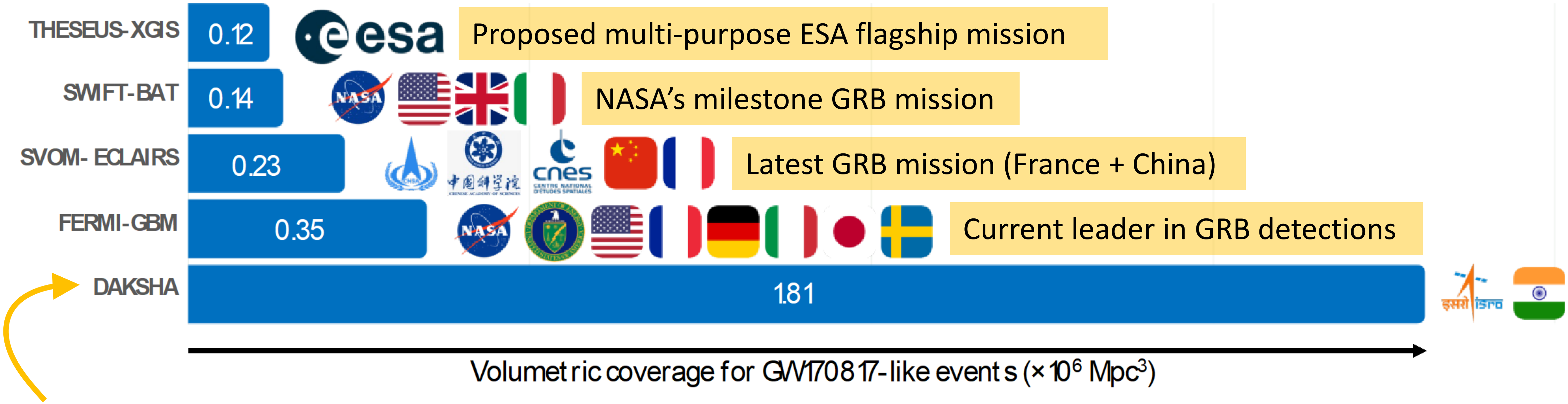
- Lot of missions from China!
- Less sensitivity and coverage than Daksha







Comparing select missions



Future leader in GRB and transient studies!

Comparing missions

- Daksha has the highest volumetric survey reach of any mission
- BAT-like sensitivity over the entire sky
- Wider spectral band

Bhalerao et al., 2024, ExA, 57, 24
https://arxiv.org/abs/2211.12055

Mission name	Energy range (keV)	Effective area (cm^2)	FoV Sky fraction	FoV (sr)	Range Mpc	Volume Mpc^3	Sensitivity (1-s, 5σ) erg cm^{-2} s^{-1}	Sensitivity (1-s, 5σ) ph cm^{-2} s^{-1}	Reference
Daksha (single)	20–200	1300	0.7	8.8	76	1.27×10^6	4×10^{-8}	0.6	This work
Daksha (two)	20–200	1700	1	12.6	76	1.81×10^6	4×10^{-8}	0.6	This work
Swift-BAT	15–150	1400	0.11	1.4	67	0.14×10^6	3×10^{-8}	0.5	(a)
Fermi-GBM	50–300	420	0.7	8.8	49	0.35×10^6	20×10^{-8}	0.5	(b)
GECAM-B	6–5000	480	0.7	8.8	65	0.81×10^6	9×10^{-8}	—	(c)
SVOM/ECLAIRs	4–150	400	0.16	2	70	0.23×10^6	4×10^{-8}	0.8	(d)
THESEUS/XGIS	2–30	500	0.16	2	45	0.06×10^6	1.7×10^{-8}	—	(e)
THESEUS/XGIS	30–150	500	0.16	2	58	0.12×10^6	5×10^{-8}	—	(e)
THESEUS/XGIS	150–1000	1000	0.5	6.2	20	0.02×10^6	45×10^{-8}	—	(e)

Daksha – Indian Eyes on Transient Skies

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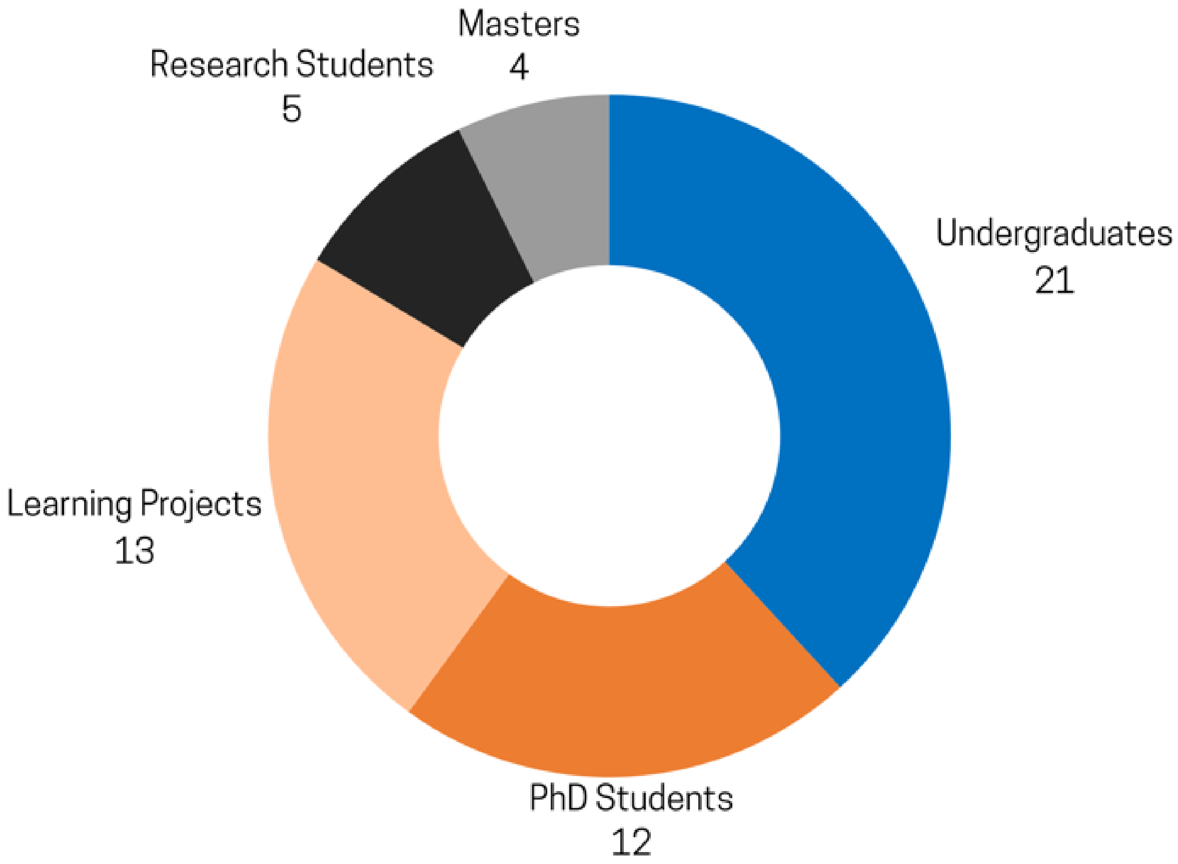
Education

- Over 55 students trained, and counting!



- Workshop at ASI 2024
- 80 students attended
- Simulator + mock data shared
- All materials online!

Outreach: Thousands of students every year!

Impact in India

- Science: Astrophysics, Solar studies, Atmospheric sciences
- Visibility: Daksha will become the de-facto starting point for studying high-energy transients for all international scientists
  - ISRO and Indian Astrophysics gets high visibility and standing
  - Currently NASA Fermi / Swift have such status
- Synergy: Strong support from large projects including LIGO-India, SKA, etc
- Education and outreach: Core institute (IITB) well-known for teaching!
  - Many student research projects completed, more under way
  - Workshops and rich online content
  - Daksha can seed an ecosystem of well-trained space scientists

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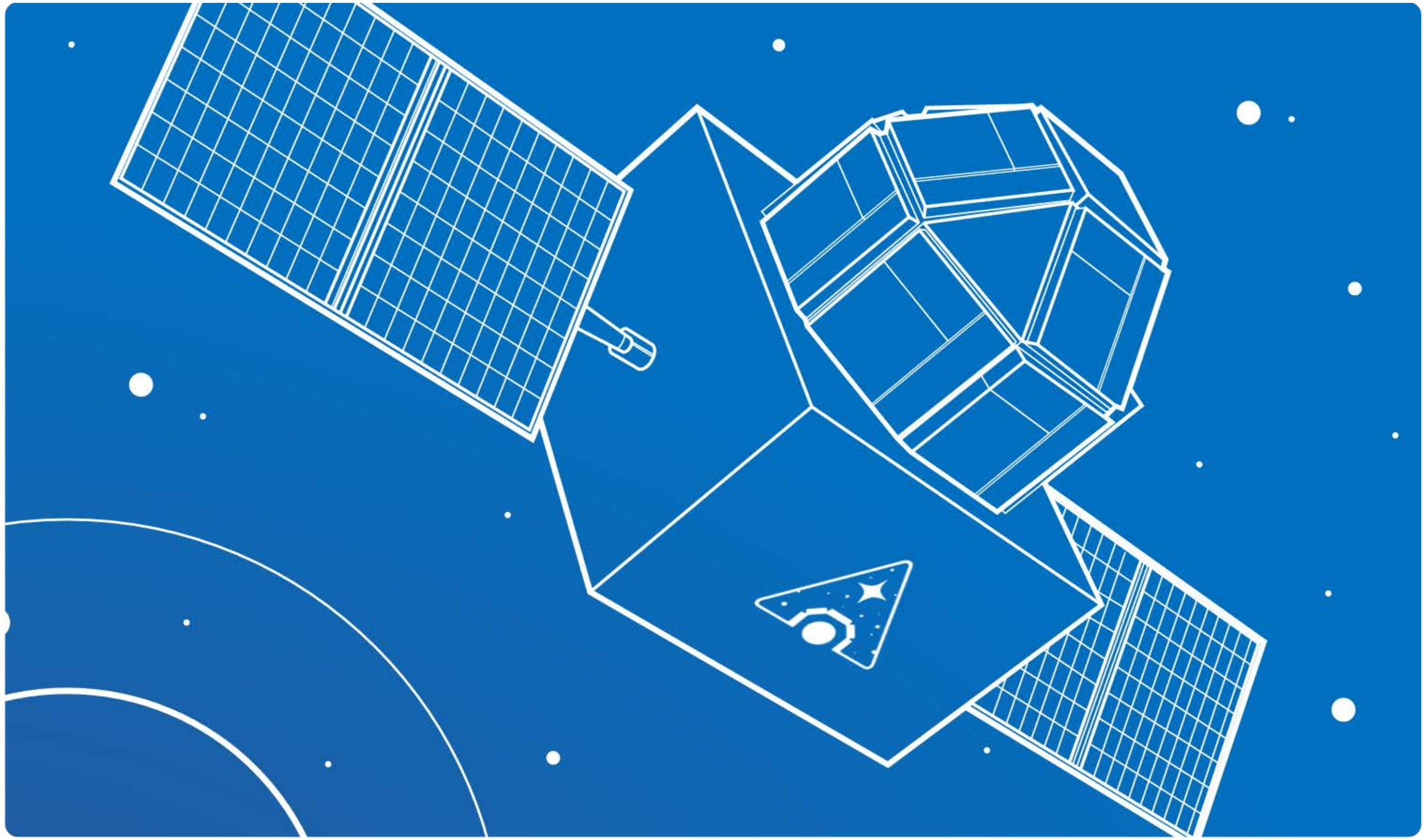

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Comparison with Einstein Probe

- Figure taken from Yuan et al, 2015
    - Proceedings of "Swift: 10 Years of Discovery" (Proceedings of Science; ed. by P. Caraveo, P. D'Avanzo, N. Gehrels and G. Tagliaferri).
    - arXiv:1506.07735
- Yuan 2022 quotes **2-3 cm^2** for central spot of PSF
    - Chapter in "Handbook of X-ray and Gamma-ray Astrophysics"
    - arXiv:2209.09763
- Daksha LE effective area ~ **32 cm^2**
    - Single satellite all-sky median
- Effective Area × FoV = 9.24×10^5 cm^2 deg^2
    - ~30× higher than EP

Einstein Probe Weimin Yuan

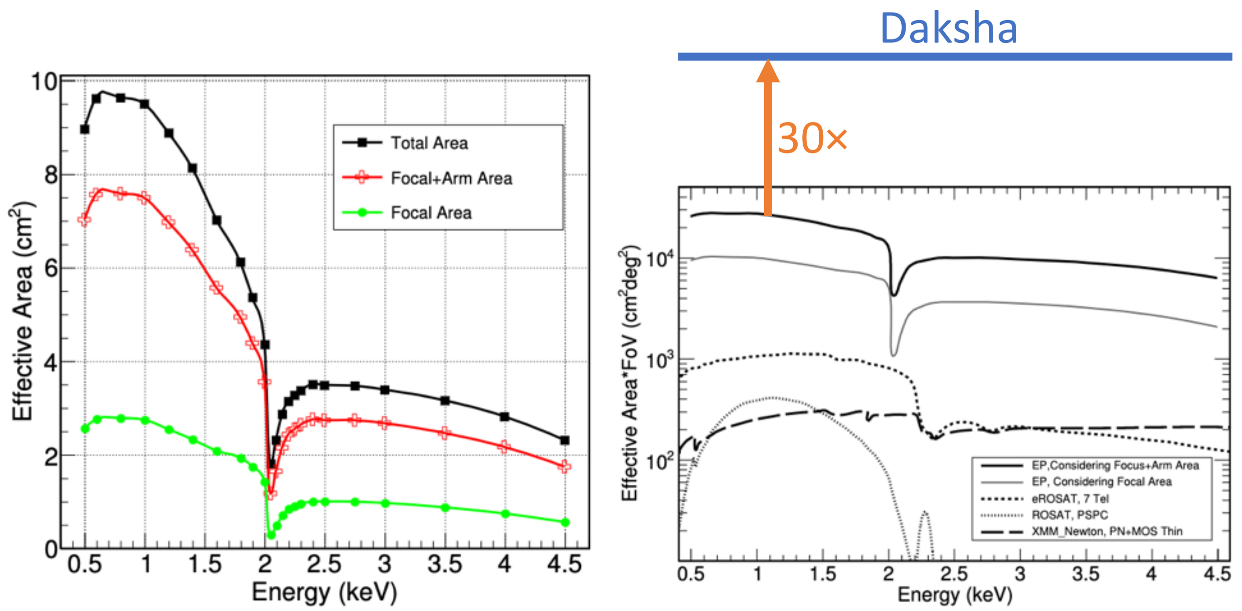

Figure 2: (left) Effective area curves for EP/WXT with GEM detectors, for the central focal spot (green), central plus the cruciform arms (red), and total (black; plus unfocused X-rays as diffuse background). The MPO arrays are coated with Iridium, and have surface roughness of ~0.55 nm and the tilts of pores following a Gaussian distribution with σ=0.85 arcmin. The detector is filled with Xenon gas, and has a thin window of a 40 nm-thick Si_3N_4 foil coated with 30 nm-thick Aluminum. (right) Grasp of WXT, in comparison with other focusing X-ray instruments. Figures adopted from Zhao et al. (2014) [17].

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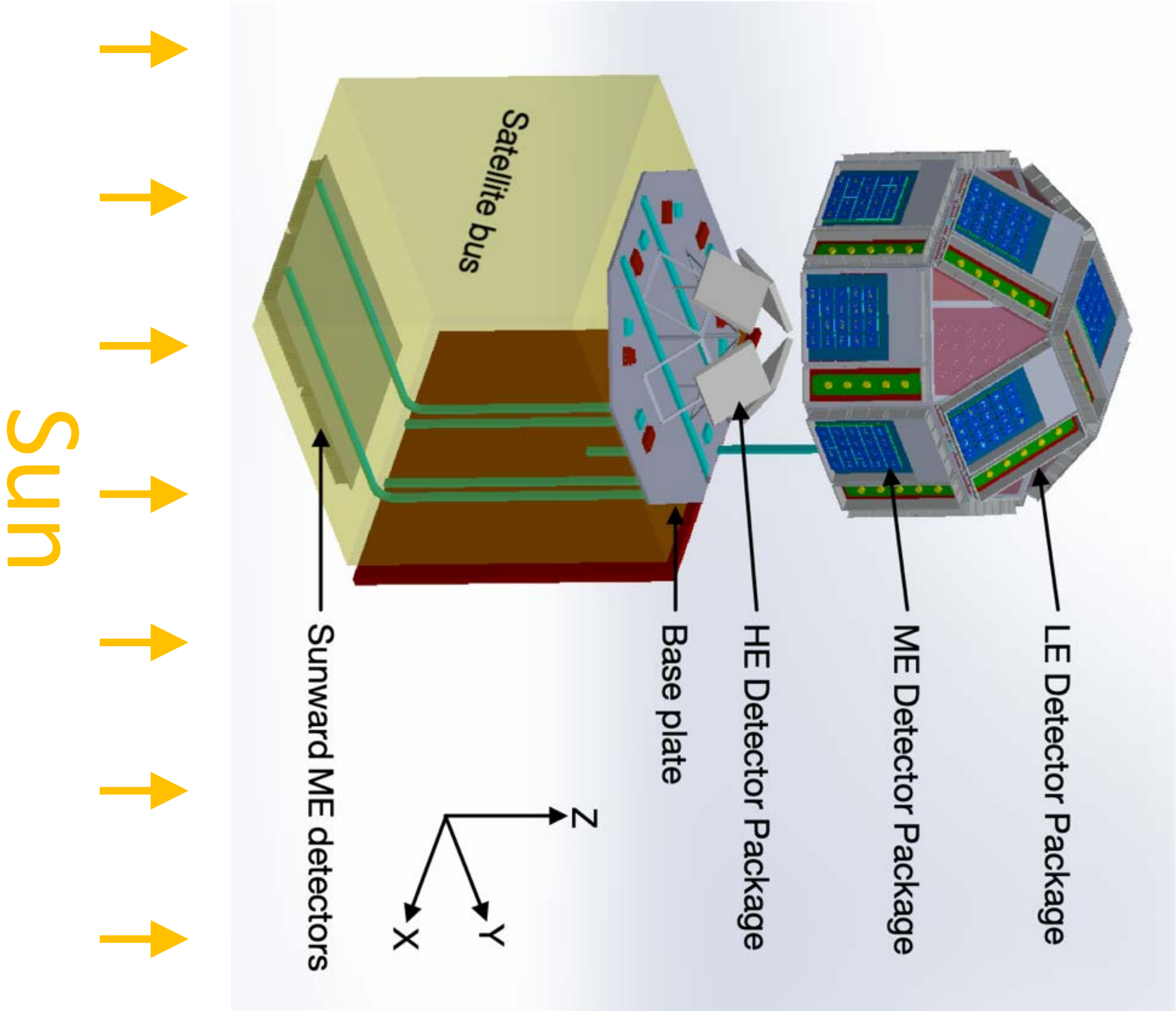
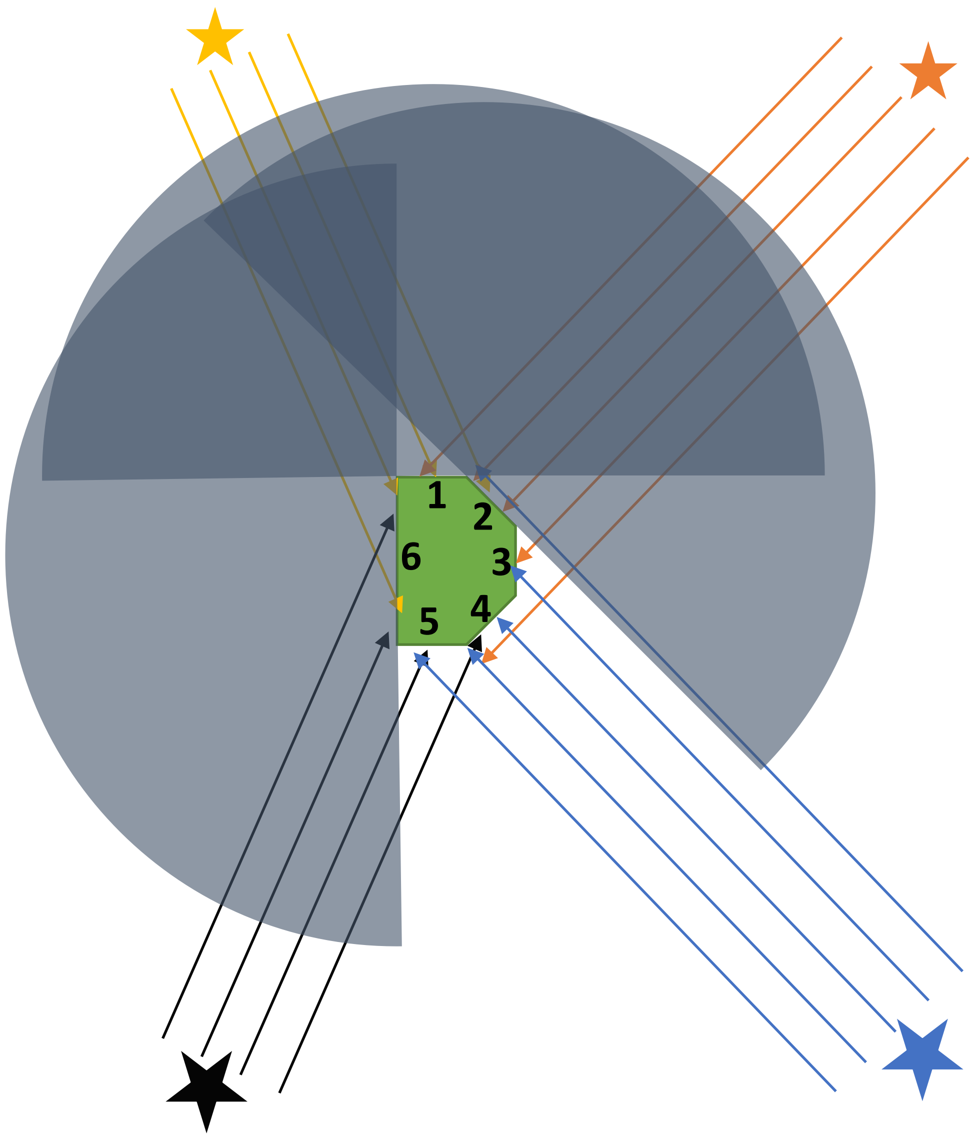
Orbit details

- Dome continuously points away from Sun
  - LE detectors never see the Sun
  - 4 ME packages point to sun
- 1 degree per day rotation to stay pointing away from Sun.
- Pointing accuracy needed ~ 1°, knowledge better than 0.1°
- Preferred: no repointing even for data download



Coverage



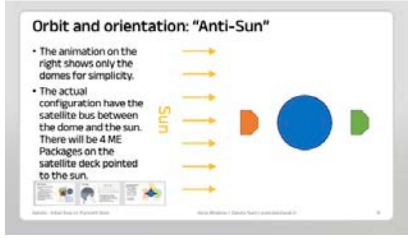
Detect + Localise						
★	1	2	×	×	×	6
★	1	2	3	×	×	×
★	×	×	3	4	5	×
★	×	×	×	4	5	6

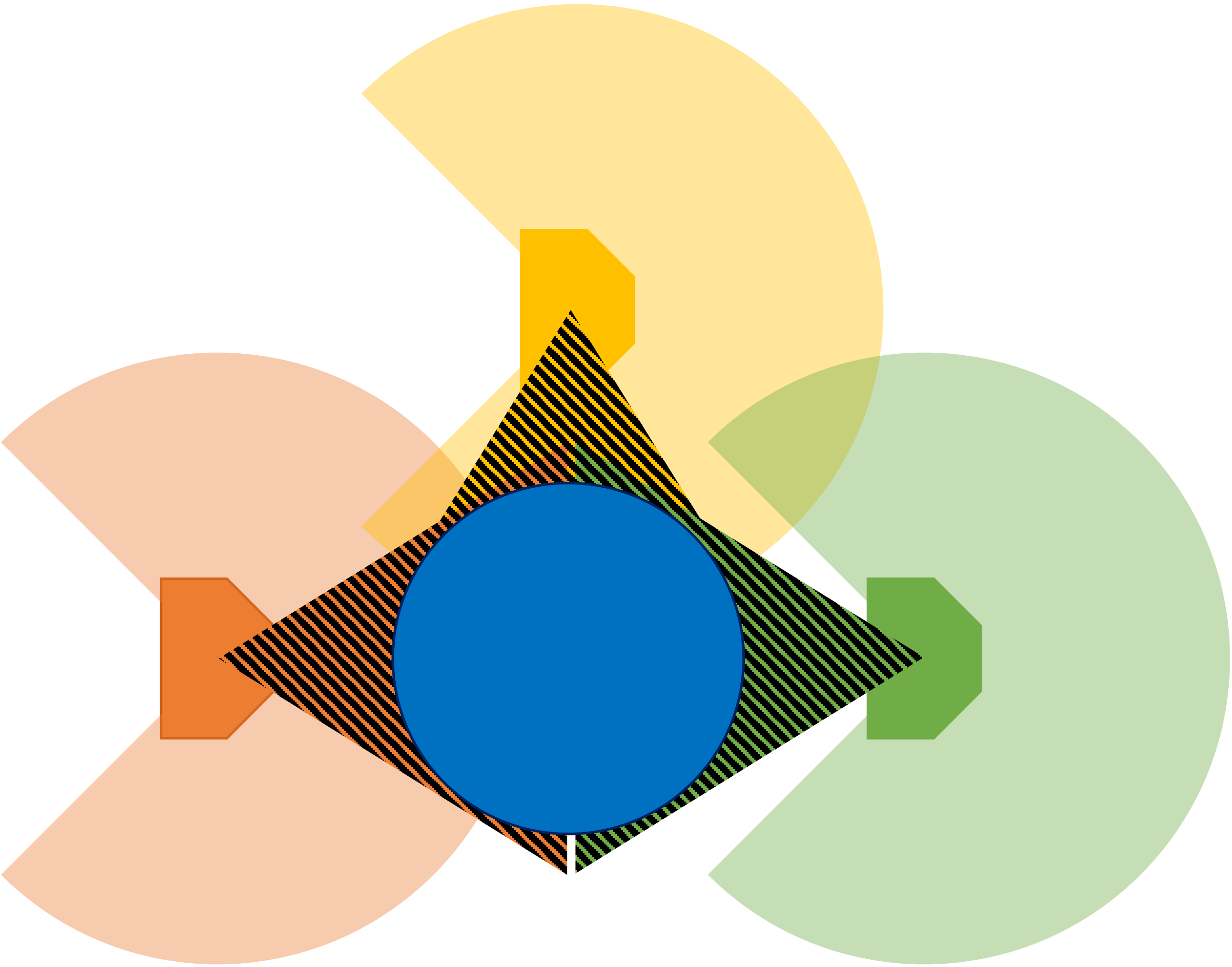
- Each package has 2π coverage
- All put together give 4π coverage
- LE coverage on left side lower as face 6 does not have LEPs
- Reduced by Earth Occultation

Low Energy Packages + Earth Occultation

- Position-dependent variable coverage
- For single satellite:
  - Maximum ~ 70-80%
  - Minimum ~40-50%

- Other satellite compensates!





Coverage ~ 40-50%

Coverage 70-80%

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Indian Eyes on Transient Skies!